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EDITED BY GERALD LEACH

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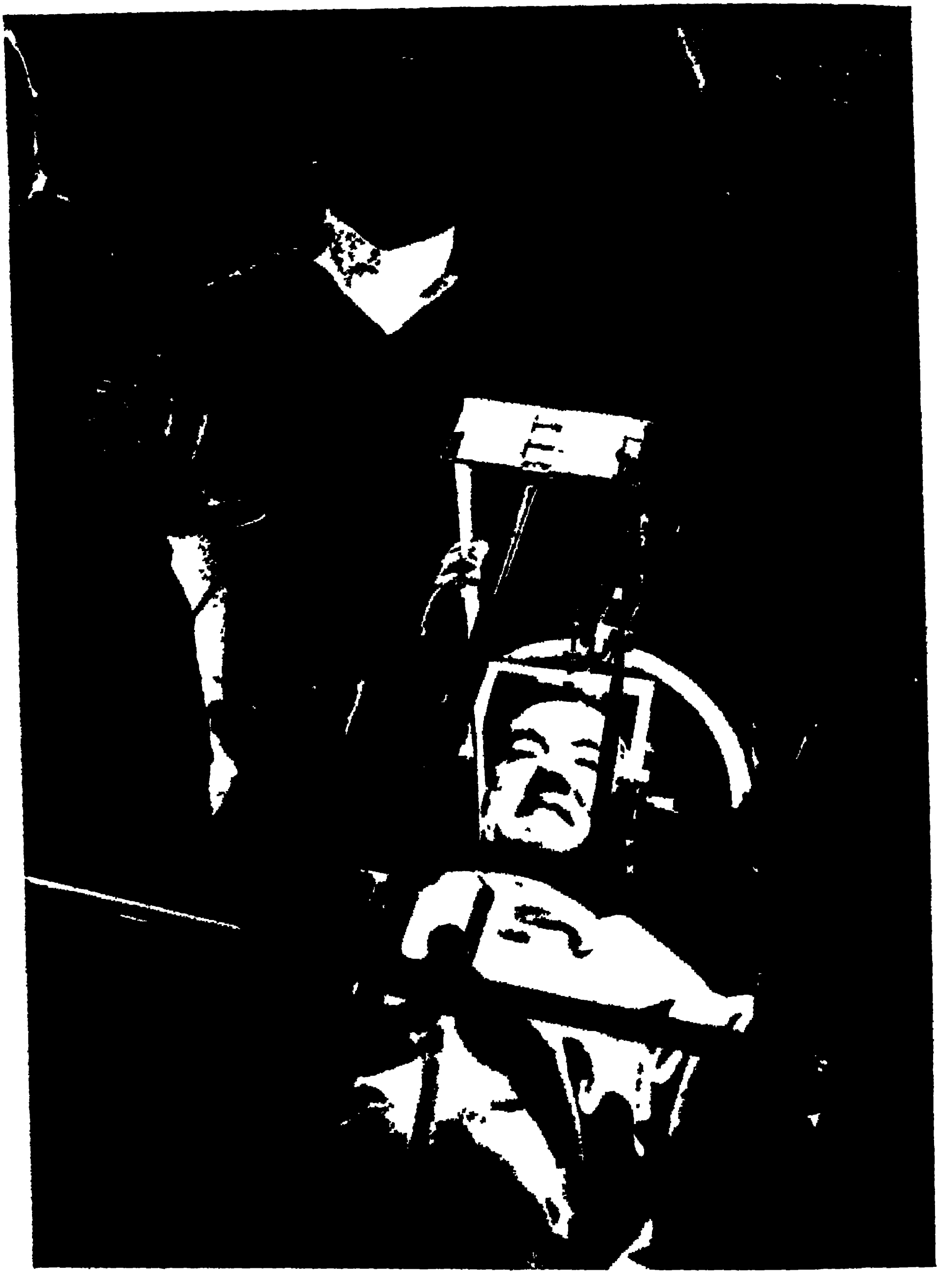

Frontispiece: An operation for Parkinson's Disease, which causes hand tremors, has been successful. The tremors have stopped for the first time for many years (*see also* Pl. XIX).

THE PROGRESS OF SCIENCE

IN AID OF
SURGERY

Tony Osman

WITH FRONTISPIECE AND
16 PAGES OF PLATES
AND 10 DRAWINGS BY
ELIZABETH WINSON

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Contents

Plates

In Text

To Val

Author's Note and Acknowledgments

THIS is an account of some of the ways in which scientific advances have made surgical operations safer, easier, and in some cases, possible. In a book of this length there is obviously not space to include all the scientific developments and practical applications in surgery. Similarly, the acknowledgments cannot mention everyone who has helped in the preparation of the book—there are far too many of them, and in any case medical ethics prevents the names of many of them from being given. I hope that they will accept this general acknowledgment as thanks, though I know it to be inadequate.

June 1966. TONY OSMAN.

I. *Investigating the Patient*

SURGERY in the nineteenth century was a very dangerous treatment, used only as a last resort. The percentage of patients who died after an operation by Joseph Lister illustrates the risk. He was one of the greatest surgeons of all time, and he was said to have saved more lives than had been thrown away in all the wars of history; he introduced antiseptic surgery in the 1860's and cut the death-rate from amputations by two-thirds. Even so, 15 per cent of his patients died. Operations were a frightening prospect, and never used if any other treatment seemed at all likely to succeed. Yet they were often a necessary risk. A leg that was broken could be set, but if the bone came through the skin the wound would usually become septic. There was no cure for sepsis; the only treatment was amputation. Another condition that necessitated an operation was the development of a cyst—a fluid-filled swelling—or a tumour, which is a solid growth. Either of these might become so large that they caused unbearable pain. The extreme risk of an operation would have to be taken.

One hazard of surgery was the pain of the operation. Various drugs, and alcoholic drinks, had been tried as anaesthetics since very early times—probably as far back as prehistory—but they were never very effective. Modern anaesthesia dates from the nineteenth century, when the first successful anaesthetics—chloroform, ether, and nitrous oxide—came into use. These anaesthetics helped to reduce another danger—shock. Surgical shock occurs when the body is injured. The first reactions—faintness, pallor, and nausea—may pass quickly, but there is a second stage that can prove fatal. Blood or plasma (part of the blood) stops circulating and goes into other parts of the body, and this can be fatal. Secondary shock becomes even more likely if there has been a lot of bleeding, and the operation itself can cause this. The possibility of death by bleeding made all operations difficult, for they had to be done quickly rather than carefully. Some operations were impossible;

nobody considered operating on the heart or the large blood vessels.

The other danger was sepsis. Lister's was the first attack on surgical infection. He used carbolic acid as an antiseptic, often sprayed on the seat of the operation by a pump, and this was the antiseptic surgery that cut deaths after amputations by two-thirds (Pl. I). However, this method enveloped the surgeon and the patient in unpleasant and possibly dangerous clouds of a disinfectant that might also actually harm the open wound. It would obviously be much better to keep the operation free from infection than to try to kill the germs once they were there. This is the technique of aseptic surgery, where the operating theatre, the instruments, and the surgeon and his assistants are all so clean as to be free from germs (Pl. II). This method, although effective in many cases, is inadequate for operations on parts of the body that are themselves infected. These may be organs, such as the appendix, that are internally infected, or they may be wounds that have become septic. It has become possible to operate easily on such places only since the development of the sulphonamides and the antibiotics. Even with these new drugs there are still gaps in the germ-killing armoury.

Despite these gaps, surgery is now very safe. New-born babies can be operated on for defective hearts, and old people for defective glands, and they can all recover to lead normal lives. Surgery has become a part of medical treatment rather than a last-chance life-saver.

Diagnosis

The surgeon's first problem is to decide whether surgery is necessary. The ideal would be for him to find out what is wrong and to plan his operation without opening the body to have a look. Feeling for lumps and listening for a faulty heart valve are helpful, and the surgeon can learn much about a broken bone by looking at the limb and moving it gently; but the greatest advance in diagnosis came from Röntgen's discovery of X-rays (Pl. III).

Soon after their discovery X-rays were in use in medicine. They went easily through soft tissue and would affect a photographic plate on the far side; but harder objects, such as bone, left a shadow. Probably the first diagnostic X-ray picture taken in Britain was one that showed a needle in a woman's thumb.

This was taken in University College Hospital, London, in 1896. These early X-ray machines were feeble—they might need an exposure of half an hour—and could be used for investigating only fractures and foreign bodies. The machines were soon improved so that short exposures could be used; the chest, for example, could be photographed while the patient held his breath. Modern machines use exposures as short as 0·02 sec.

As well as affecting a photographic plate, X-rays can make a screen coated with calcium tungstate glow. For some purposes this moving picture is more useful than a photograph, since the heart or the lungs can be seen in action and, if the patient has been prepared, the stomach and the bowels. This kind of picture is used in mass radiography. It would be very expensive to take actual X-ray pictures of the entire population, because the films used are life size, but the glowing screen can be photographed with a miniature camera fairly cheaply. Anyone whose picture suggests disease is re-photographed on a full-sized machine.

It is extremely difficult to interpret X-ray pictures of soft tissues, since all that can be seen are faint shadows of varying depth. What is often needed is a 'contrast medium' that can be put into an organ so that it becomes opaque to X-rays. Barium sulphate was the first of these to be adopted. If a patient swallows a 'barium meal'—a thick paste of barium sulphate and water—the stomach becomes opaque to X-rays. As the meal travels through the system, the duodenum (the part of the small intestine that immediately follows the stomach) also becomes opaque. The stomach and the duodenum are both places where ulcers can occur, and these ulcers, called gastric and duodenal ulcers respectively, show up fairly clearly on X-ray photographs taken after a barium meal.

Other contrast media were soon discovered. They had to be harmless as well as being opaque to X-rays, and diodone is now used for all organs outside the digestive system. It is a liquid that can be injected into the windpipe—the trachea—so that it runs downwards into the lungs and makes the bronchial tree (the network of tiny tubes in the lungs) visible under X-rays. It can also be injected into the spinal canal (the long tube in which the spinal cord lies) to show any obstructions or distortions of the canal. And it can be injected into the bloodstream so that the blood vessels of, say, the kidneys and spleen become opaque and show any tumours that are there.

In the last few years two further improvements to X-ray techniques have made them even more valuable to the surgeon. One is a way of producing a brighter image on the X-ray screen (Pl. IV). Bones show up very clearly, but the soft parts of the body, even when a contrast medium is used, give a clear image only when they are photographed. Electronic engineers have now devised an image intensifier, so that the X-rays can be used during the operation. A further advance was an image-retaining X-ray screen (Pls. V, VI). This gives an 'instant' picture by using an electric method of showing where the X-rays strike. The picture can be preserved for up to half an hour, or it can be erased and a new one made.

X-rays have their limitations. First, they give no information at all about some organs and, secondly, there are some occasions when they are dangerous. There is, for example, a possibility of harming the child in a pregnant woman by using X-rays on her body. Fortunately the surgeon has other techniques available.

One of these uses ultra high frequency sound. Echo-sounding, or sonar, is well established as a way of finding out what is beneath a ship at sea. Sound waves are sent out from the ship and are reflected by the sea bottom, or by fish or any other objects in the water. The reflected sound waves can be analysed so as to show where they were reflected and, often, what they were reflected by. A similar technique is now widely used to look for flaws in pieces of metal. The use in medicine is basically similar (Pl. VII).

Short pulses of high frequency sound are focused into parallel beams and sent into the body of the patient. The beams are partly reflected by any layer where the 'sound texture' changes. This will occur between any sections that have differing abilities to transmit sound. The echoes from the layers are picked up and made visible on the screen of a cathode ray oscillograph. This can be set so that it gives a two-dimensional map of the part of the body underneath the sound source. In the earlier models, transmitter and receiver were moved across the body by hand, and this method is still used for investigating the brain, where it is particularly effective in locating abscesses and growths.

A more refined version is used on the abdomen. Sound is not reflected efficiently from a layer that is not perpendicular to the sound waves, and most of the organs inside the body would therefore give an ill-defined echo. Dr Ian Donald of the University of

Glasgow has developed a scanning technique in which the sound-emitting probe is rocked through a small angle as it moves across the patient's body; both movements are made mechanically. This device has proved to be very effective in diagnosing abdominal swellings in women (Pl. VIII). It is quick, it can be used without the patient leaving her bed, and, unlike X-rays, it cannot harm the child in a pregnant woman.

An interesting technique that has recently been developed is 'isotope scanning'. The patient is given a radioactive substance in such a way that it is taken up by the particular organ that is to be investigated. The radiation is too weak to be harmful to the patient, but it can be detected by a scanner that gives a picture of the organ, or rather of the radioactive substance absorbed by it. Any abnormality—such as a tumour—will show itself as a variation in the density of the picture of the organ (Pl. IX).

X-rays, ultrasonic waves, and isotope scanning give only indirect information about the body. The surgeon also needs as much direct information as he can get to supplement this. The cardiac catheter gives him a way of finding out directly what is happening inside the heart. It was devised by Dr W. Forssmann in 1929 when he was working in Eberswalde in Germany. He came across a print in an old veterinary journal that showed a surgeon putting a tube along the vein of a horse to sample its blood. Forssmann decided to find out if it would work with human beings. He tried it on a dead body, and then, as no one would help him, on himself. He found that he could slide a tube into a vein in his arm and push it along until it actually went into the right atrium of the heart (Pl. X). To prove that he had done it he then walked to the X-ray unit of his hospital and had photographs taken. He maintained that the tube could be used to find out how efficiently the heart was working, by taking samples of blood from the inside of the heart. The technique was not taken up in Germany, and Forssmann himself led a relatively undistinguished life for years (he even gave up medicine for a time). But two Americans—A. Cournand and D. W. Richards—did develop the idea. They found that the catheter could be used to find the composition of the blood before it was sent round the lungs. Their work was extended, and it was found that the catheter could be worked past a heart valve to investigate the blood in the right ventricle, and even the blood in the pulmonary artery that led to the lungs. Samples of blood could

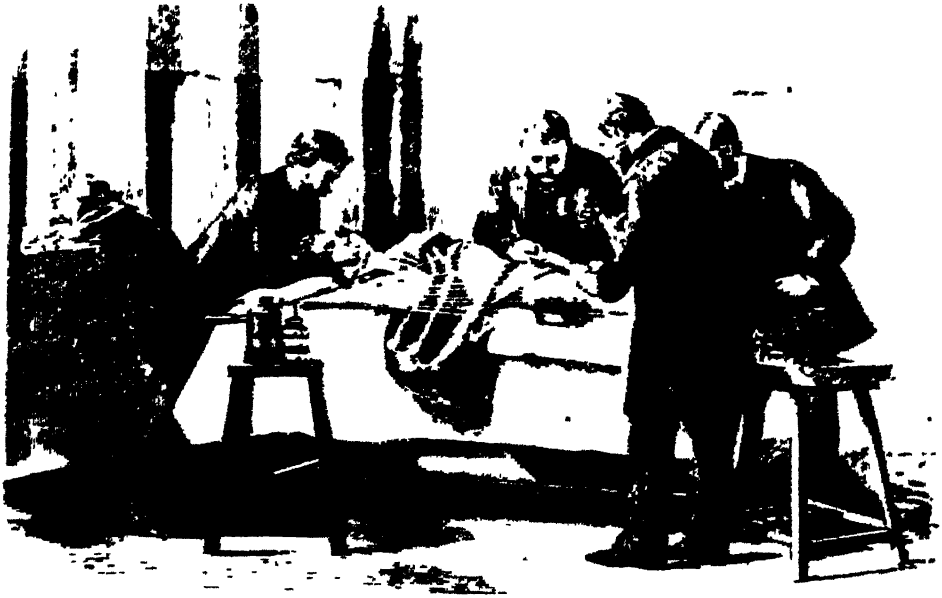
be withdrawn and analysed to find out how much oxygen and carbon dioxide the blood contained. This showed how efficiently the heart was working, and if samples from the heart itself showed that blood was mixing in the heart, this indicated a hole in what should have been an impermeable wall. Even in its simple form, the cardiac catheter gave a lot of valuable information about the working of the heart (Pl. XI). The invention and development earned Forssmann, Cournand, and Richards a Nobel Prize.

So far only the right-hand side of the heart could be investigated. The catheter could be pushed only along a vein—that is, in the same direction as the blood flow—and the vein that joins the heart and the lungs was inaccessible. It seemed risky to try to get to the left side of the heart by working against the blood flow, as the catheter might cause a clot or damage a heart valve (Fig. 1).

This problem was solved by Dr J. Ross, of Bethesda, Maryland, who invented a catheter that consisted of three concentric tubes. The whole catheter was thin enough to be slid along a vein until it entered the heart. The outer tube shielded a needle that had the third tube inside it. In use all three tubes are slid along a vein until the end is in the right upper heart. The needle is eased through the heart wall, and the very fine tube at the centre is pushed forwards to take samples of the blood and to measure its pressure. This tube can then be worked through the mitral valve so as to reach the lower left heart and sample the blood there. The cardiac catheter is now a routine device that is used for investigating the condition of the heart whenever heart surgery is contemplated.

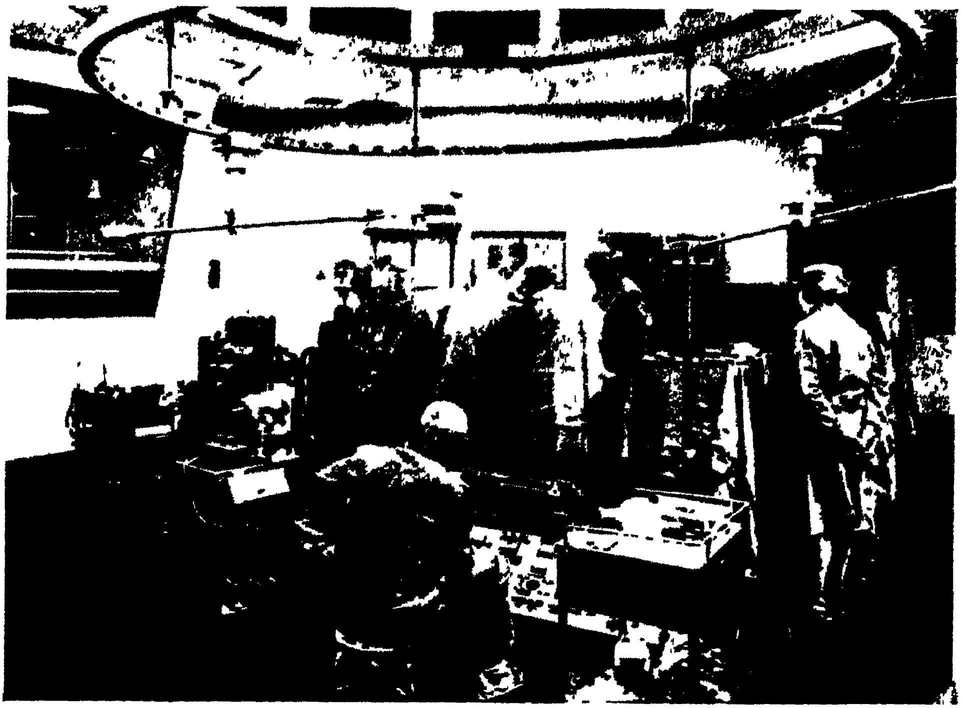
Though the catheter gives direct information about the blood in the heart, it can give only indirect information about the condition of the heart wall and heart valves. These can now be looked at directly with the fibrescope. This was invented by Dr H. H. Hopkins of Imperial College, London, and is based on the fact that a beam of light that is shone down a glass rod will be totally internally reflected and will stay inside the rod even when it is bent. This applies even to a very thin rod in the form of a fibre.

The fibrescope is essentially a bundle of fibres bound together. This bundle can be eased along a vein in the same way as a catheter. Once one end has entered the heart, a light is attached to the other. This light travels down the fibres and lights the inside of the heart, and an arrangement of reflectors and lenses at the outward end makes it possible to photograph the heart. A similar arrangement



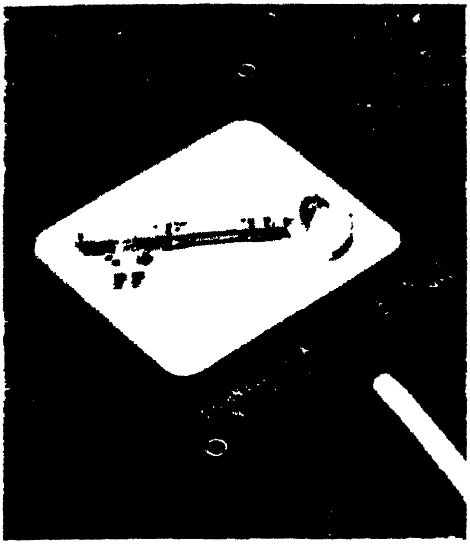
I In Joseph Lister's day, in spite of his introduction of the antiseptic spray, surgery was highly dangerous.

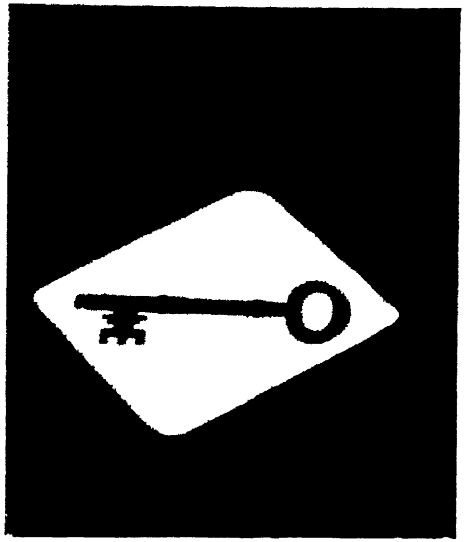
II In the modern operating theatre surgery, in this case using a heart-lung machine, is very safe.



III One of the earliest X-ray photographs, taken in 1896.

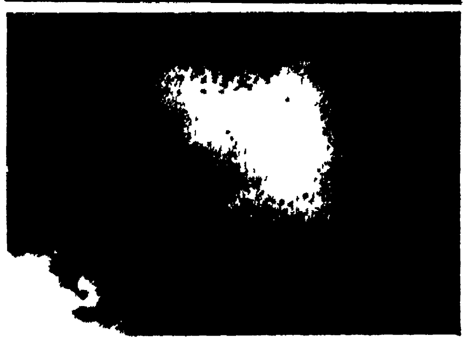
IV One of the latest X-ray techniques uses television principles, whereby the image on the fluorescent screen is converted into an electronic display for immediate viewing, sometimes on a number of screens.





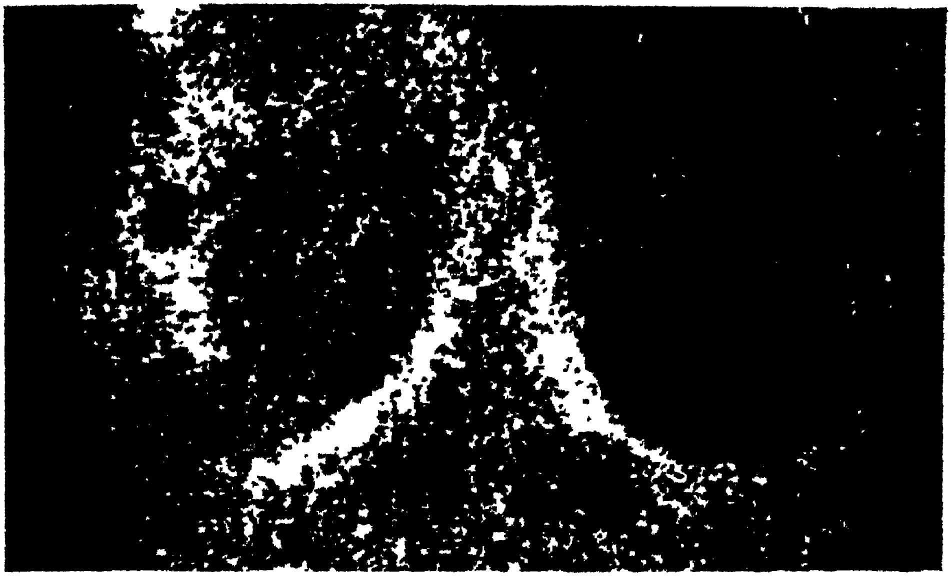
V, VI The image-retaining panel, which when electrically treated retains the X-ray 'photograph' of any object for up to half an hour.

VII, VIII, IX Two modern diagnostic aids. Echo-sounding can be used (*below, left*) in the diagnosis of abdominal complaints. This photograph shows both a hand probe and the more powerful scanning probe. The map resulting in this one shows (*right, top*) an ovarian cyst. *Right, below:* Isotope scanning. More of the radioactive isotope is absorbed by the tumour than by the rest of the brain.



X The surgeon threads a cardiac catheter through a vein to reach the heart chambers, so that suspected heart defects can be diagnosed, and watches its progress on a television screen.

XI An X-ray photograph showing one end of a cardiac catheter lying in the heart.

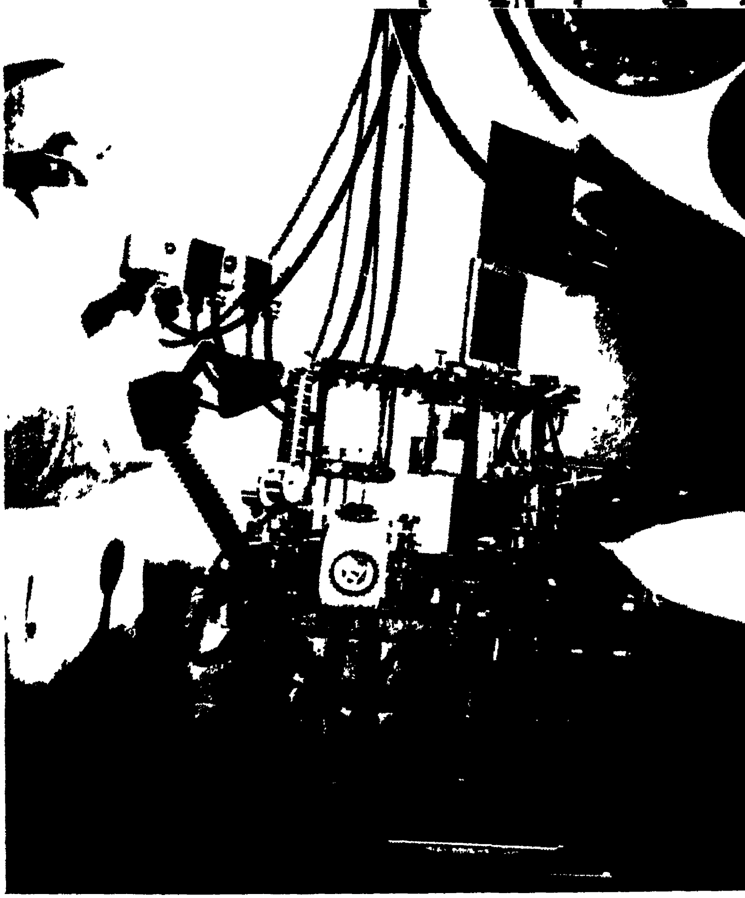


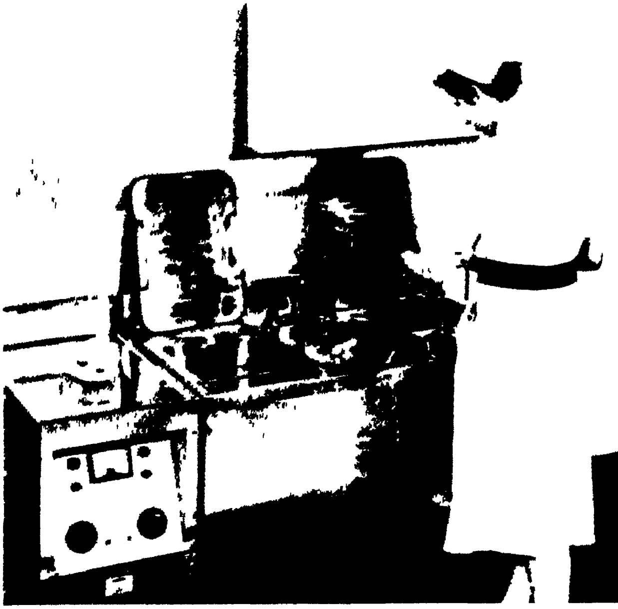
XII, XIII Photographs taken by the heat camera show up parts of the body which disease or deeply-seated injury has made hotter than the surrounding parts. *Above:* The darker (hotter) area indicates a tumour of the left breast. *Below:* A heat camera picture of this badly burned leg shows areas needing skin grafts.

XIV X-ray picture of patient who has swallowed a telemetry 'pill' (radio transmitter) which will transmit signals telling the surgeon the condition of parts of the body which are otherwise inaccessible. The transmitter in this case was attached to a thread tied to a tooth.

XV *Right:* Anaesthesia in the early sixteenth century. Alcohol being administered to a patient in a monastic hospital.

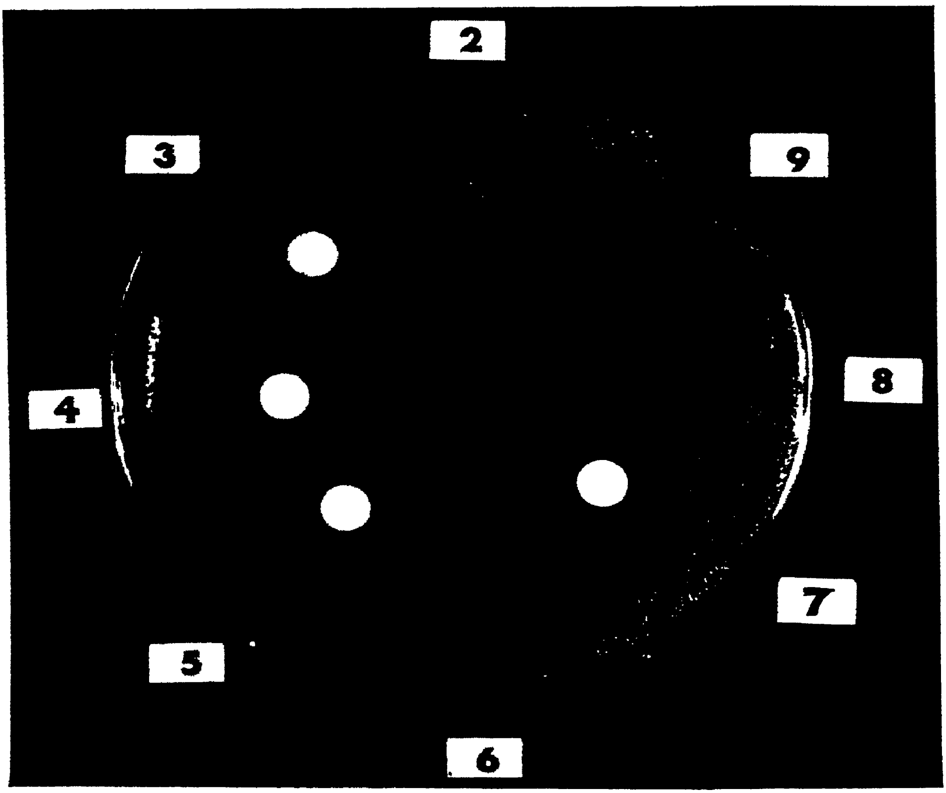
XVI *Below:* Anaesthesia today. The anaesthetist uses a whole range of techniques to protect the patient and make the surgeon's task easier.





XVII Equipment for cleaning surgical instruments by ultrasonic vibration, which can reach otherwise inaccessible surfaces.

XVIII A test to discover which of nine sulphonamide drugs are most effective against bacteria. Paper discs impregnated with different drugs are placed on a plate of nutrient material on which bacteria are growing. Dark areas around the discs indicate that bacterial growth has been prevented by the drug. In this test drugs No. 1 (centre) and No. 7 were most effective: Nos. 3, 4, 6, 8 and 9 were slightly effective; Nos. 2 and 5 had no effect.



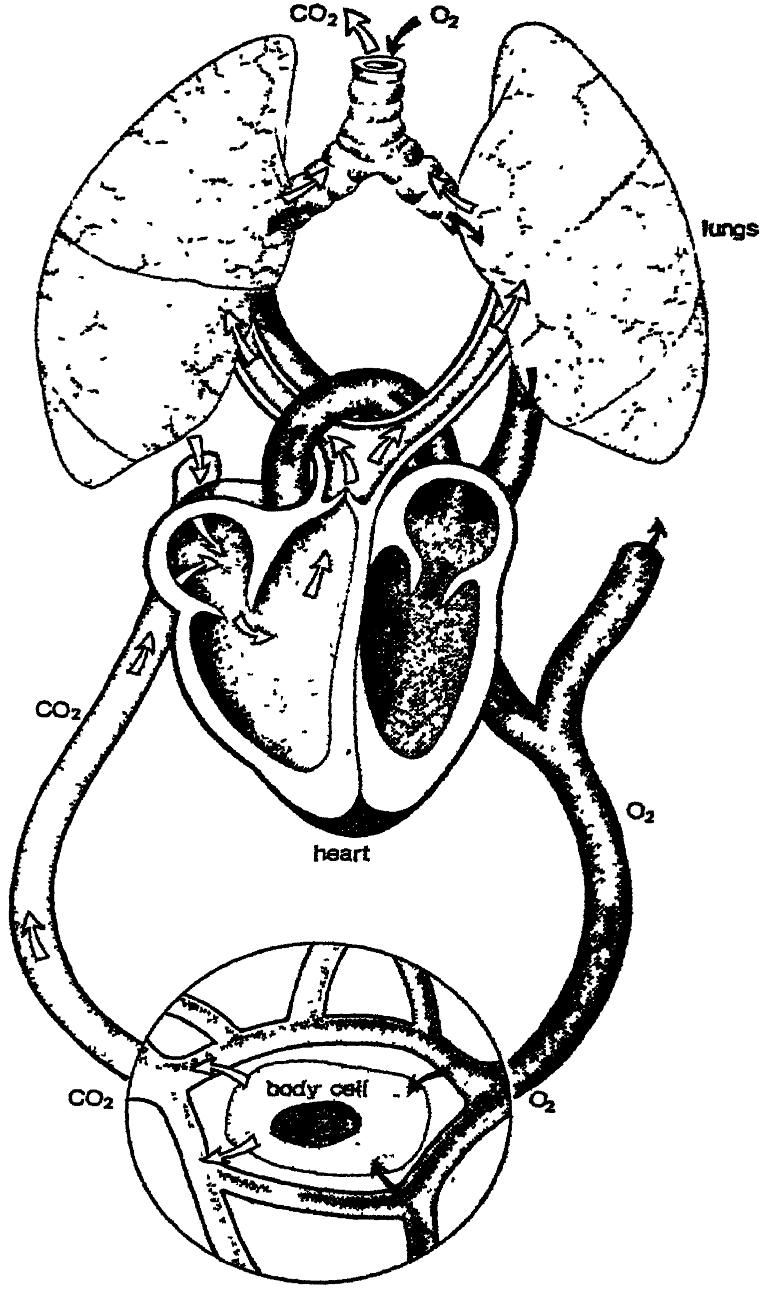


Fig. 1. Schematic representation of the human heart-lung system. The cardiac catheter is worked along a vein with the flow of blood (white arrow) and into the heart. Black arrows show the flow of blood in the arteries.

can be used to investigate any organ that can be reached along a tube. The bladder is one example—the fibrescope can be so fine that it can even look into the tubes joining the kidneys to the bladder. Another example is the lungs, which can be reached down the windpipe. To check the location of the fibrescope the surgeon can watch its movement by X-rays.

The heat camera has also turned out to be a valuable aid to diagnosis. This relies on the fact that some parts of the body become, under certain conditions, hotter than those around. One such condition is cancer; cancerous lumps on the body are as much as 5° C. hotter than harmless lumps, and the hotter they are the more likely they are to break up and lodge in other parts of the body. The heat camera is a sensitive electronic thermometer that 'scans' the patient and records the hotter parts as dark patches. Effectively it takes a picture of him by his own heat (Pls. XII, XIII). This is an ideal kind of diagnostic method, since it does not involve doing anything to the patient. Unlike X-rays, for example, it cannot harm him. Veins that are near the surface and badly burned parts of the body are also rather hotter than the surrounding parts, and will be detected by the heat camera.

Another valuable technique that has been developed recently is that of telemetry. This is a means of transmitting radio signals from parts of the body that were relatively inaccessible, so as to get information about the conditions there. Much of the development is due to R. S. Mackay of the University of California.

His first aim was to make a radio transmitter that could be swallowed. He made one that was a cylinder about two centimetres

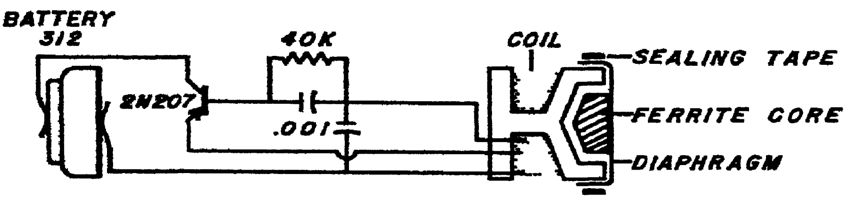


FIG. 2. An electrical circuit for a telemetric pill, which transmits the effects of changes of pressure on the core. A telemetric pill can be less than 2 cm. in length.

long and rather less than one centimetre in diameter—about the size of a large vitamin tablet (Pl. XIV and Fig. 2). This would transmit pressure changes inside the body. One use is to measure

the pressure changes in the large intestine that are caused by peristalsis, the waves of muscular contraction that force food and waste products through the alimentary canal. Peristalsis stops after surgery on the stomach. It is important for the health of the patient that it be restarted as soon as possible, and a number of drugs have been tried in an attempt to find one that would speed this up. Unfortunately it is difficult to tell from the outside whether it has restarted. A telemetry pill swallowed before the operation, or put into the canal during it, will transmit signals about the pressure waves as soon as the movement starts. The pressure is measured by its effect on a small ferrite (magnetic) core in the transmitter, which also has to contain a battery (Fig. 2). This has limited the degree to which the size of the pill can be reduced. One transmitter was made recently that used the digestive juices as the liquid part of the battery, and needed only electrodes dipping into them. Unfortunately it turned out that the voltage varied according to the composition of the gastric juices, and that this depended on what the patient was thinking about. If he thought about lamb chops, for example, he secreted more juices, and the transmitter gave an inaccurate reading.

The original aim was to make a pressure-measuring transmitter that could be swallowed. The current aim is to make one that can be embedded in the eye. In a disease called glaucoma the pressure of the fluid in the eye rises, causing the eye to become hard rather than resilient, and eventually damaging it so as to produce blindness. The pressure is affected by both psychological and physical factors, and a transmitter that could be embedded and left in the eye for some time would show which factors had the most effect. Research workers under Mr Mackay are trying to make a 'passive' transmitter—one powered by current induced in it from outside—that will measure 1 × 1 × 2 mm.

Other changes than those of pressure can be measured. The temperature near the ovaries of some mammals increases at ovulation, when a fertilizable egg is released. Research workers have implanted transmitters that reveal this increase in monkeys. The aim was to increase the likelihood of fertilization—the monkeys were kept for breeding—but a similar instrument would give information that would be valuable in studying impregnation and contraception in human beings.

Ulcers in the stomach or duodenum are revealed by blood in the

stools, but in about one-fifth of the cases it is not possible to tell exactly where the bleeding is. There are now several forms of transmitter that can be swallowed, and that will pass along the digestive system and give out a signal when they reach the site of the bleeding. Their progress can be followed either by direction-finding radio or by X-rays. Another pill that measures the acidity of the digestive juices is valuable in studying changes that can cause ulcers.

Telemetry as an aid to diagnosis is still experimental, but the amount of information the surgeon can have to help him is rapidly increasing. Diagnosis is still an art rather than a science, and most of the signs and symptoms used are not measurable in any exact way. However, the increasing use of exact measurements suggests the heady possibility of diagnosis by computer. Any combination of measurements that can be related to particular diseases can be programmed on to a computer, and the diagnostic surgery of the future may automatically measure blood pressure, pulse, temperature, stomach acidity, and blood composition. A fluorescent X-ray screen could be scanned and the patterns of tumours and ulcers recognized automatically, and an automatic stethoscope would detect the irregularities of heartbeat that showed disease of the valves. Many of these machines have already been tried and are in use, on an experimental basis, for supervising the progress of patients after operations. The automatic diagnostic surgery lies a long way in the future.

II. *Anaesthetics and Antisepsis*

FOR a simple operation the patient is put to sleep with an injection and then kept unconscious with an anaesthetic that is poured on to a mask over his nose and mouth. Anaesthesia for a difficult operation may be very much more complex. Throughout, there is a tube held in the patient's throat, emerging through his mouth. This tube is usually connected to a battery of gas cylinders, and the anaesthetist controls these gases so as to keep the patient unconscious but well throughout the operation, which may last for hours. If the chest has to be opened for the operation, the patient will no longer be able to inflate his own lungs and breathe; the anaesthetist must breathe for him. In an operation on the heart the blood will be side-tracked and led through a mechanical heart so that the real one can be stopped; the blood will be cooled so as to lessen shock and to lower the body's needs for the oxygen carried by the blood. This is all the responsibility of the anaesthetist (Pl. XVI). He has come a long way from the pad soaked in chloroform that he used a hundred years ago.

The patient knows nothing of all this. In the early 1930s he would be wheeled into the operating theatre and the anaesthetic would be administered as a gas or a vapour. He would, for a few moments, fight the feeling of suffocation that resulted and he would eventually succumb, slowly it would seem to him, wondering if he would be fully unconscious before the surgeon started to cut. Nowadays his last conscious feeling is the prick of a hypodermic needle as he lies in his bed or on the hospital trolley. A drug—a barbiturate—is injected and the patient soon becomes peacefully unconscious. He will know nothing until he wakes, hours later, back in his bed.

Surgery has often been limited by the body's reaction to pain, since more than a certain amount of pain is intolerable to the patient. The surgical shock that acute pain causes may prove fatal, and, in addition, a conscious patient will have such tense muscles that the surgeon cannot get past them in his operation.

There were no successful anaesthetics used before the nineteeth century. The early Arab physicians are believed to have used opium and hyoscyamus, administered by mouth, and mixtures of these drugs with others were used on a 'soporific sponge', from which the patient inhaled, from the ninth century. Throughout history alcohol has been used to stupefy patients before operations (Pl. XV). None of these methods was very successful. Mesmerism was tried in the early nineteenth century by James Esdaile. He successfully carried out about two hundred painless operations in India, but the method failed when he tried it in Scotland on his retirement.

The first successful anaesthetic used in an operation was nitrous oxide. Sir Humphry Davy, who discovered the gas, found that he could stop his own toothache by inhaling it, and suggested in 1799 that it could be used as an anaesthetic. Nobody took up the suggestion, and the properties had to be rediscovered by Horace Wells, a dentist of Hartford, Connecticut. He had one of his own teeth extracted while 'under' the gas, which he later used for a series of extractions on other people. During a crucial demonstration the patient groaned, and although he said afterwards that he had felt nothing, the demonstration was considered to have failed. However, the gas became accepted as an effective anaesthetic for minor operations, and is still used by dentists. For long operations it has to be mixed with oxygen to avoid asphyxiating the patient, and even then it does not give deep unconsciousness and proper muscular relaxation.

One of Wells's former pupils, William Morton, was at the unsuccessful demonstration. He decided to try ether as an anaesthetic and used it in 1846 during a tooth extraction. In October of that year he used ether during the removal of a tumour from the neck. The successful use of a general anaesthetic marked the real start of anaesthesia in surgery, and ether itself was a popular anaesthetic until recently. The objections to it are that a fairly large dose has to be used, and that it irritates the lining of the bronchial tubes. This can set up a cough that puts a painful strain on the surgical wounds. Ether is also dangerously inflammable.

Dr James Young Simpson pioneered the use of chloroform. He had used ether in operations, but in 1847 he turned to what he hoped would be a less objectionable chemical. By the end of the year chloroform had virtually replaced ether for a while. It is difficult to believe that there was at this time a vigorous opposition to the use of

anaesthetics, partly because they were hazardous, but largely on religious grounds. Pain, it was held, was part of the divinely ordained burden of man. Those who had ever needed surgery were usually, and not surprisingly, in favour of anaesthetics, and general opposition died away after Queen Victoria allowed chloroform to be administered to her during the birth of Prince Leopold in 1853.

The clinical objections to chloroform remained. Pure chloroform can poison the heart muscle, and can damage the liver. Further, it is unstable, and decomposes slowly to form the deadly poison gas phosgene. None of the other anaesthetics was perfect, but each of them was highly successful, and their use completely altered surgical technique. Sheer speed became less important, and a wider range of operations became practicable. It was this rise in the total number of operations, and hence in the number of fatalities, that showed just how bad surgical technique was and how great was the need for improvement.

The search for better anaesthetics went on. Cyclopropane had advantages but was dangerously inflammable; divinyl ether produced unconsciousness quickly but was unsuitable for maintaining it. Trichlorethylene—'Trilene' is its trade name—was not very effective in making the patient unconscious, but it turned out to have one valuable property—it abolished pain before the patient became unconscious. This meant that it could be self-administered, and was ideal for midwifery. The woman in childbirth administers her own anaesthetic, using a small inhaler with a face piece and a valve that is closed by a spring. When she needs the anaesthetic she presses the valve and inhales. After a few breaths the pain disappears; if she continues to inhale she begins to lose consciousness and releases the valve; this closes, and she becomes conscious again.

In some very difficult modern operations there has been a new approach to anaesthetics. The early anaesthetics produced unconsciousness, and if the dose were sufficient they also gave insensitivity to pain and muscular relaxation. All three effects are needed, but there is no need to rely on one substance for all of them.

The patient is usually made unconscious with a barbiturate. This technique has been used for a long time, and it may be used even for simple operations, for it avoids the unpleasantness that many patients feel when a mask is applied. It acts very quickly. The patient is asked to count after the drug is injected and when he

stops counting the surgeon knows he is unconscious. There is no sensation of losing consciousness—it happens too quickly—so that the patient has none of the frightening slow descent into sleep that he used to feel if, say, ether were used on its own. He is so unaware of the process that he may, on waking, continue counting where he left off. The drug acts quickly, but the anaesthesia is not deep enough for the surgeon to work. The main anaesthetic is now used, but even so the muscles may be insufficiently relaxed for some operations. Curare, or rather drugs derived from it, relaxes these.

Curare is extracted from the bark of a tropical tree and is used by South American Indians as a poison to tip arrows. It paralyses the voluntary muscles (those that we can control), and the victim dies of suffocation because the breathing muscles no longer work. This relaxation of the muscles is ideal for the surgeon, so long as the patient can be kept alive until the effect of the drug has worn off. This is done by forced breathing, using an endo-tracheal tube (a tube that is passed through the patient's mouth and held in his windpipe, or trachea, by inflating a rubber cuff). The other end of the tube goes to a reservoir bag and then to the cylinders that supply the anaesthetic, to keep the patient asleep, and oxygen to keep him alive. A cylinder of carbon dioxide, which acts as a stimulant in small doses, will also be available. After he has used the barbiturate and the curare, the anaesthetist then takes over the patient's breathing. The bag is squeezed to drive gases into the lungs; as it expands, the exhaled gases are purified so that they can be recirculated.

An obvious advantage of the tube is that it lets the anaesthetist work at a distance from the patient. He is therefore not in the surgeon's way, especially during plastic surgery on the face or during brain surgery. Operations on the chest show its other great advantage. Normally the lungs are kept expanded because the pressure in the part of the chest where they are, the thoracic cavity, is below atmospheric pressure. If the chest is opened without any precautions being taken the lungs collapse. They can be kept inflated by pumping gas into them through the endo-tracheal tube, and this has made operations on the lungs themselves possible, as well as the increasingly important operations on the heart.

The ability to use curare safely during operations led to a search for more powerful drugs for producing muscular relaxation—

relaxant drugs, as they are called. These are synthetic compounds that have similar structures to curare and are three times as powerful. Succinylcholine chloride is even more powerful, but it works in a different way. The nerve whose message causes a muscle to move acts by liberating a substance called acetylcholine. This in turn starts the muscle contraction. Curare and the curare-like compounds block the nerve endings; succinylcholine chloride neutralizes the acetylcholine's effects. It is more powerful but shorter acting.

The task of the anaesthetist has been made easier by the introduction in 1956 of halothane—'Fluothane' is its trade name. This was produced by Imperial Chemical Industries Ltd as the result of a programme that deliberately aimed at making a powerful, safe, non-irritant, non-explosive general anaesthetic. It fulfilled these demands to a great extent, and is now probably the most widely used general anaesthetic. Anaesthetists have largely stopped using a battery of substances, each contributing its own part to the total effect, and use a preliminary barbiturate to avoid alarm, followed by 'Fluothane' and relaxants if necessary.

The anaesthetist's first aims are to get the patient unconscious, insensitive to pain and with his muscles relaxed, without harming him. The combination of drugs does this. He must give the surgeon as much space to work in as possible. The breathing-tube achieves this. The next problem is to give the surgeon as much time as possible to work in.

Bleeding limits the surgeon's work partly because of the results of the loss of blood—but this can be offset by transfusions—but as much by the way that the blood stops the surgeon from seeing what he is doing. Any large arteries that are cut during the operation can be slipped or tied, but it is not possible to do this with smaller blood vessels, which bleed steadily into the operation site. To make matters worse anaesthetics—ether in particular—raise the blood pressure and force the blood more vigorously out of the wound. This also hinders the clotting that would naturally stop the bleeding.

In man the blood pressure is kept up by muscles that surround the arteries. Since these muscles are not part of the voluntary system they are not affected by curare. The nervous system that controls them is called the autonomic nervous system, and along its pathways it has 'junction boxes'—ganglia—that control particular

areas. These ganglia can now be blocked by drugs (such as hexamethonium) that are close relatives chemically to those that act like curare. By using these ganglion-blocking drugs to produce the same sort of relaxation in the involuntary muscles that curare produces in the voluntary ones, the anaesthetist can now greatly reduce the amount of bleeding.

As we have seen, the anaesthetist has to make the surgeon's task as easy as possible. The major side of his activity is to make sure that the patient is unharmed by the surgery. Opening the blood vessels, altering the blood pressure, surgical shock—all of these affect the supply of oxygen to the cells of the body. The brain is irreparably damaged if its blood supply is interrupted for more than two or three minutes. This would severely limit the time available for operations in which the heart is opened, but there are now two ways of avoiding brain damage. One is to use an auxiliary blood pump to replace the heart; the other is to reduce the amount of nutrition that the cells need. They will then survive longer before they are damaged by a reduced blood supply.

All chemical processes run more slowly at lower temperatures, so the activity of the cells will be cut down if the body is cooled. This occurs in nature in hibernating animals, which live throughout winter without either food or water. They are, in addition, virtually not breathing. Because the activity of the cells of their bodies has almost stopped, these cells are unharmed by the lack of an oxygen supply. If a patient could be cooled to this state of suspended animation he too would be unharmed if the circulation of the blood were severely reduced during an operation.

The problem is that human beings are not intended to hibernate, and they have a number of mechanisms that resist cooling. When the body is cooled it reacts partly by resisting the loss of heat and partly by generating more heat. First, the surface blood vessels contract and the blood is driven more deeply into the body, and thus farther away from the skin where the heat is being lost. Secondly, the muscles go into an oscillation—shivering—that speeds up the cells' activities and generates heat.

Both of these mechanisms are controlled by a heat-regulating centre in the brain, and the first successful attempts at 'artificial hibernation' used drugs to paralyse this centre. In 1951 a group of French doctors, including Jolmes, Laborit, and Huguenard, used a group of drugs—chlorpromazine, promethazine, and pethidine

were among them—to paralyse the centre so as to cool the body of a patient for an operation. The cooling was essentially passive—the drugs were administered and the patient was left for a couple of hours without blankets to cool off. The temperature dropped only slightly, about 4° F., but this reduced the body's need for oxygen by some 20 per cent. Unfortunately the method was unpredictable, for it was difficult to know exactly what dose of drugs to use. Too little, and the temperature barely dropped; too much, and the temperature fell so far that it was difficult to reverse.

In modern practice active cooling is used. This method ignores the heat-control centre. The body warms itself by shivering, and this is prevented by using curare. The patient is then cooled either directly, by wrapping him in a cooling 'blanket' with a constant circulation of cold water through it, or by cooling his blood. To do this a tube is inserted into the main vein that carries blood into the heart from the upper part of the body. This tube is connected to a pump that sends the blood through cooling tubes and back into the heart through the other main vein. This delicate technique will be described in more detail in the next chapter, together with the associated equipment, the heart-lung machine.

This machine was for some time a rival to cooling methods—hypothermia. It was devised particularly for operations on the heart to get round the two major difficulties that had prevented surgeons from operating there: the danger of damaging the tissues by depriving them of the oxygen carried in the blood, and the bleeding that occurred when the heart was opened. Both of these could be avoided if the heart were by-passed for a while, and the blood pumped round artificially through a heart-lung machine. At first these machines were used as an auxiliary pump while the surgeons operated on the still-beating heart; but as they became more refined they were used to replace the heart while the operation went on. Today, techniques have improved so far that surgeons can stop the heart from beating during the operation and restart it afterwards.

The battle against infection

The general story of Lister's work is well known. Surgery before his time was used as a last resort, partly because it was so painful. Another reason, possibly the main one, was that the cutting open of any part of the body very frequently led to sepsis, which caused

a great deal of suffering and often death. Lister, while working in Glasgow, realized that the suppuration of an unhealthy wound was a result of 'decomposition', and the work of Pasteur suggested, in about 1865, that this was caused by microscopic organisms carried by the air. He therefore tried to destroy the germs that the air carried to the wound, although even then he realized that the germs carried by the surgeon's hands and those in the wound itself were also dangerous. To do this he used his famous carbolic acid spray. Although he first used it in 1870, he had been using antiseptics in surgery for some years before this, and the frequently quoted figures which show that he reduced the deaths following amputation from 45·7 per cent to 15·0 per cent refer to operations mainly without the carbolic acid spray. Lister himself became a determined but unwilling user of a modified version of the spray—the atmosphere that it produced was unpleasant and dangerous to the patient, to the surgeon, and to his staff—and was reluctant to abandon its use, although he soon came to realize that it was very unlikely that any dangerous micro-organisms were carried by the air. If they were carried by the surgeon's hands and his instruments, infection could be prevented by extreme cleanliness. This approach, that of aseptic surgery—in which no infection is allowed into the operating theatre—is still in use. The instruments are boiled, the surgeon works through a detailed 'scrubbing-up' routine, no one with any septic infection is allowed into the theatre, and the exposed tissues of the patient are handled only with instruments.

There are two sources of infection that evade these precautions. Patients are sometimes brought to hospital in an infected and often septic condition, and the micro-organisms that are responsible can remain to infect future patients. They are responsible for occasional and usually small outbreaks of infection in the theatre. The source that cannot be kept from the operating theatre is a septic part of the patient himself. Accident victims, and people wounded in war, are infected at the actual site of the operation, and so are those suffering from peritonitis (infection of the abdomen); operations on the bowels also release quantities of infected material. These operations need modern antiseptics, which destroy the bacteria without harming the patient. More accurately, these drugs usually stop the bacteria from growing and multiplying, while the original bacteria are killed off naturally in the patient's body.

One important group of these anti-bacterial drugs is the sulphonamides. Their history starts in 1935 when a red dye, 'Prontosil', was found to cure patients suffering from streptococcal infections. It was soon found that it was only a colourless part of the dye, sulphonilamide, that was active, and this activity was very high. The drug worked against, for example, meningitis, pneumonia, and puerperal fever, all diseases against which previous drugs had been powerless. Enormous numbers of variations on the basic sulphonilamide formula were tried in an attempt to get more active drugs. May & Baker Ltd, chemical manufacturers, tried a number of different ones before they found a successful compound, which they called M & B 693. Pl. XVIII shows how sulphonamides are tested.

This research work was helped by an understanding of the way the drugs worked. The basic formula of all these hundreds of sulphonamides was very similar to that of an acid which is essential to the growth of bacteria. In some way or other the similarity was sufficiently close for the bacteria to be 'fooled' by the drug, so that they used the drug rather than the normal acid in their metabolic processes. But unlike the acid, the drug was useless to the bacteria, which were therefore killed. The drugs are powerful and valuable, and although they are extremely dangerous to some people, or if taken in large doses, they are widely used.

Penicillin is the best known of the other group, the antibiotics. They are compounds that are produced by moulds that live largely in the soil, although their spores float in the air and grow easily on suitable places, such as old loaves of bread. It was the effect of some spores of the mould *Penicillium* that floated on to a dish where colonies of staphylococcus bacteria were growing that led to the discovery of the drugs. Fleming, in 1928, noticed that the colonies of bacteria near the place where the spores had settled died off. He confirmed his experiments, suggested that the mould gave off some anti-bacterial substance, and abandoned the work for a time. Eleven years later Florey, at Oxford, decided to find out whether the substance had any use in medicine. He, with Chain and other workers, eventually extracted it, and found that it was indeed extremely valuable; the purified extract was called penicillin. The next problem was to produce the drug on a large scale, and then to produce it relatively cheaply. All of these problems were eventually solved, and the remarkably successful career of the drug started.

There were still problems. In general medicine the drug was not effective against the bacteria that cause pneumonia and typhoid, or against viruses. In surgery it was invaluable to begin with, like the sulphonamides. But like them it became slightly less useful as resistant strains of bacteria, particularly of staphylococci, developed. As the drugs became more widely used these strains became, by a normal evolutionary process, the predominant ones. The development of resistance, and the desire by the drug companies to make an antibiotic that was better than any competitors, led to experiments with an enormous number of substances produced by moulds. Many of them are effective against particular infections, and some of them, methicillin and cloxacillin are examples, act against resistant strains of bacteria. These all secrete an enzyme, penicillinase, that attacks the nucleus of the penicillin molecule. In methicillin and cloxacillin this nucleus is so altered that the enzyme does not attack it. The battle against infection is by no means won, but the surgeon's task has been made very much easier, and the patient's chances very much better, by these new drugs.

None of these new drugs was used to disinfect surgical instruments, and until recently these were treated with crude disinfectants or by boiling. This was fairly effective in removing casual infection, but it was not satisfactory in removing all infections introduced by the patient; it can be made more effective with ultrasonic vibration (Pl. XVII). A particularly resistant infection was infective hepatitis. This is a liver disease that is carried by a virus, and it was found to be easily spread from patient to patient by hypodermic syringes, particularly those used for withdrawing samples of blood. The solution to the problem was to devise a cheap hypodermic syringe that could be used once and then destroyed. This syringe is made of plastic, enclosed in a plastic container, and sterilized by exposing the package to gamma-rays. Rather surprisingly it turned out to be cheaper, as well as safer, to use these hypodermic syringes and throw them away than to sterilize a conventional syringe and use it again. Hospitals are increasingly using sterilized disposable instruments.

III. New Tools and Aids to Surgery

PARKINSON'S disease is a nervous disorder that shows itself as a trembling of the patient's hands and a stiffness of his face. It is an affliction that becomes worse with time, and until recently it could be treated only rather crudely and rather dangerously with drugs. Then it was discovered that the course of the disease could be dramatically altered if a small group of cells in the thalamus—the globus pallidus—at the base of each of the cerebral hemispheres of the brain was put out of action by surgery.

Brain surgery such as this demands that the surgeon locates exactly the group of cells that he wishes to attack. They are not in exactly the same place in all patients, and the brain cannot be opened drastically enough to see them. The only way to tell if he is working on the right cells is to try; the only way to tell if they are no longer active is to see if the patient is cured. So the patient has to remain conscious throughout the operation.

The essential tool is ultra-cold liquid nitrogen. The patient is given a local anaesthetic, and a small hole is made in the skull and then in the surface of the brain. A thin metal tube, 0·08 inch in diameter, is slid into the brain, guided by a metal frame. Its progress is followed by X-rays. When it appears to be in the correct place the patient is asked to hold up his hands, which will be trembling with the disease. A drop of liquid nitrogen is pumped along the tube. If it is at the right place, the trembling will stop (frontispiece and Pl. XIX). If it does, more liquid nitrogen is pumped in so as to deep freeze the nerve cells into permanent inactivity. If it is at the wrong place, the tube is allowed to warm, and no permanent damage is done. The tube is then moved until the correct place is found (Fig. 3). The method is quick—it can stop in a minute tremors that have been going on for twenty years—and the patient may be up and about within a day, and leave the hospital within a week. It does not work with all sufferers from Parkinson's disease, but 90 per cent of those whom its inventor, Dr Irving S.

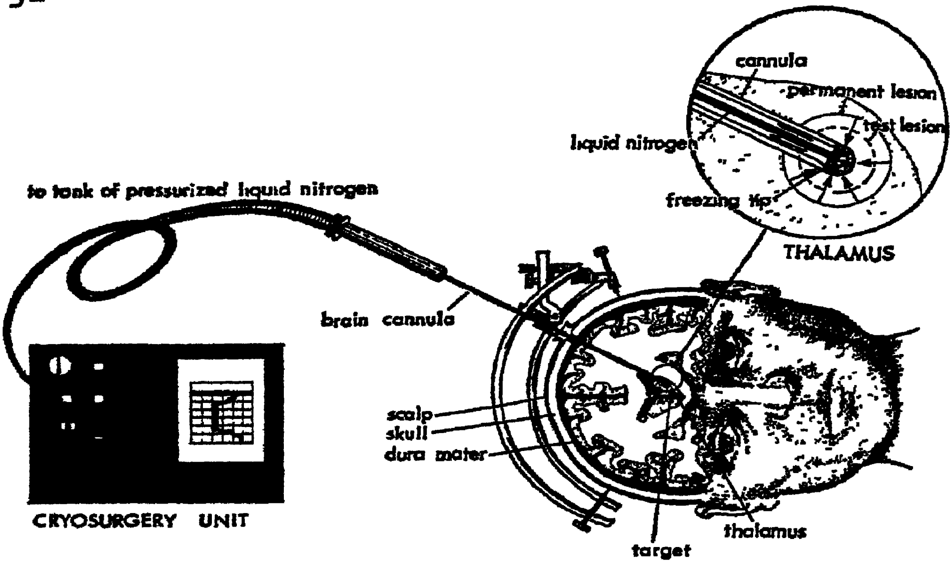


Fig. 3. Cryosurgery to cure Parkinson's disease.

Cooper of New York, has operated on have been cured, and only one in a hundred has died from the operation.

Cryosurgery—the use of extreme cold—has recently been applied, again in New York, in treating a detached retina. It sometimes happens that the retina—the screen at the back of the eye on to which the image is thrown by the lens—ceases to be held in place. The cause is probably connected with some change in the composition of the liquids inside the eyeball. If the outer layer of the eye, the sclera, is touched behind the retina with the cooled tube for a few seconds, a form of blister will develop on the retina. It takes about a week for this to disappear, but when it does so it leaves the retina firmly attached.

Another tool that has been used to re-attach a retina is the laser. This produces a coherent beam of very intense light that is of only one wavelength. It can be a very fine beam, and its energy will therefore be very concentrated. In a way the retina is ideally suited to be treated by the rays of a laser, because the lens of the eye focuses the beam on to the retina, and since this is coloured it will absorb energy from the beam. The beam is usually sent in short pulses, so that it is painless and the patient has no time to move his eyes: the retina is 'spot-welded' into place (Pl. XX). That, at least, is the principle of the idea. It has been tried at the Institute of Ophthalmology at Columbia University, under Dr Campbell, and also at

the Royal Victoria Hospital at Newcastle, in England. The tool has had some successes, but it is still difficult to decide on the correct 'dose' of light. The problem is that eyes of different colours absorb different amounts of energy from the laser beam, and while too small a dose will not fix the retina, too large a one will damage other tissues in the eye.

Another possible use of the laser is the treatment of tumours, particularly cancerous ones. The aim in all attacks on tumours is to damage them—to kill them if they are cancerous—without harming the nearby healthy tissues. The beam from a laser can be focused to a point 0·01 millimetre across, which makes it a very accurate surgical instrument, and research workers have found that it will kill tumours that have been transplanted into experimental animals. It will be a long time before this research will be known to be valuable to human beings; all that can be said at present is that it is promising.

Brain surgery is older than history—prehistoric skulls have been found with holes drilled in them, and the operations were successful, in that the patients survived; some of the skulls showed that the men had lived for years after the operation. Successful heart surgery, on the other hand, started in this century, and the operations have become straightforward and routine because of the new aids to surgery that have been produced. Some of these have already been mentioned, but not in detail.

The main problem of heart surgery is that the brain must not be deprived of its blood circulation for more than about three minutes; otherwise it is irreparably damaged. But, as we have already seen, the heart-lung machine can replace both the heart and the lungs so effectively that the heart can be stopped for the duration of a heart operation and then restarted.

But the answer is not quite as easy as this. Blood is living, and its cells would be damaged by the rough handling of a conventional pump. The pumps on the first heart-lung machines squeezed the blood along tubes into a rotating plastic cylinder that did the work of the lungs. The cylinder was packed with discs and washers which were rotated so that the blood was spread on them in a thin film. By blowing oxygen through the cylinder and therefore over the blood film, the cylinder did the work of the lungs, giving oxygen to the blood and removing carbon dioxide (Fig. 4). The machine

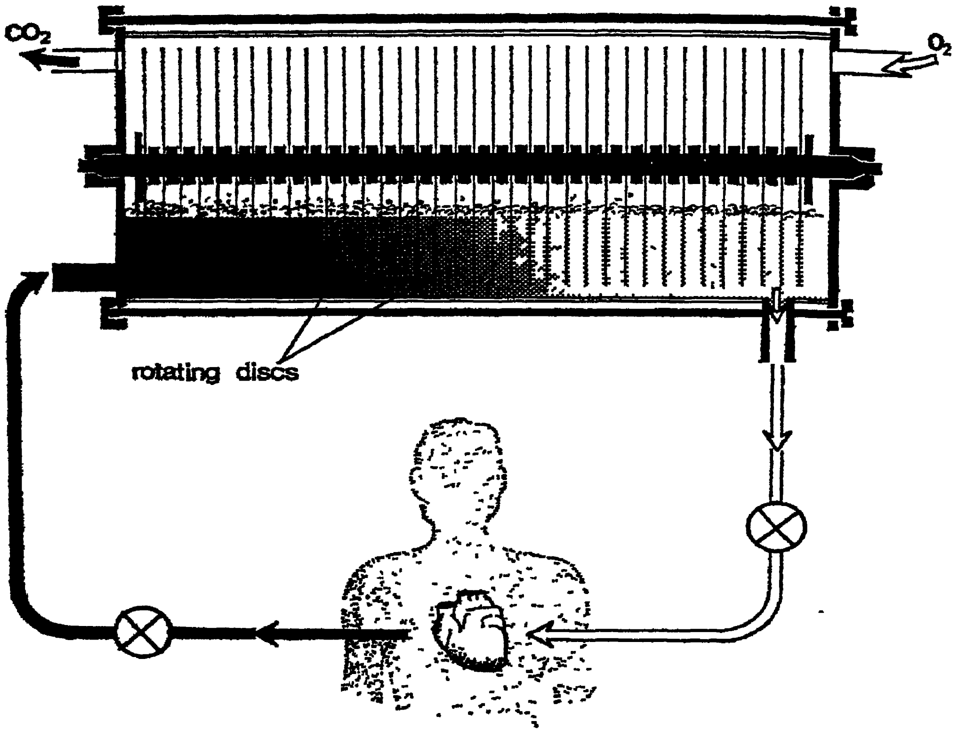


FIG. 4. Principle of the Melrose heart-lung machine.

was first used in Britain in 1953 by Dr Melrose, of the Hammersmith Hospital, London; and the operation—to repair the heart while it was still beating—was successful. Plate XXI shows a heart-lung machine in use. During the next two years Melrose perfected a technique for stopping the heart beating with a solution of a citrate, performing an operation, and restarting the heart so that it beat normally and so that there were no air-locks. He published a report on his work which produced such interest that the first actual operation on a patient using his technique was carried out in America, by Dr Willem Kolff, in February 1956. He used a much simpler heart-lung machine, where a length of semi-porous tubing acted as the lungs. The operation and dozens of successors worked perfectly. The surgeons at Hammersmith continued to improve the technique, and they demonstrated it, and the use of the Melrose machine, in an historic visit to Moscow in 1959.

The other method for avoiding damage to the brain during heart operations is hypothermia—lowering the temperature (Pls. XXII,

XXIII). The technique was developed at much the same time as that of the heart-lung machine, and was thought of as an alternative. When animals hibernate, the rates at which all their bodily functions work slow almost to a standstill. The temperature-controlling centre in the nervous system of animals that do not hibernate can be put out of action by the drugs that were described in the last chapter, and the animal's temperature, or the patient's, will then fall.

The first use of active cooling was in Minneapolis in 1952. Dr F. J. Lewis and Dr M. Taufic used a cooling method that Professor W. Bigelow had developed in Toronto, using dogs. He had cooled the dogs in a 'blanket' containing tubes through which a cold liquid flowed (Fig. 5). The dogs were unharmed. The Minneapolis surgeons cooled their patient, a five-year-old girl with a badly damaged heart, to 80° F. This took ninety minutes, but the actual operation on the heart took only five and a half—they had calculated that the cooling would allow them to take up to ten. The girl was warmed by being put into a bath of warm water for thirty-five minutes. Eleven days after the operation she was home leading a normal life. The method was gradually improved—Dr H. Swan of Denver, Colorado, developed a way of using short-wave electrical heating to revive the patient—but it was not possible to cool the patient sufficiently to give the surgeons more than about ten minutes in which to operate. And although some of the casualties were patients that no operation could have saved, others were not.

One solution to the time limitation was tried by Professor I. Boerema of Amsterdam. If the reduced blood circulation could be made to take up more oxygen than usual, the brain would remain adequately nourished for a longer time. An increase in the atmospheric pressure would produce this effect; so the answer, perhaps, was to operate in a high-pressure chamber. He found that the method worked. A later development, tried in both Britain and the United States, used pure oxygen at about twice the normal atmospheric pressure. This method has been extensively used during 1963 and 1964, and is extremely useful in heart operations. It is valuable wherever the amount of oxygen carried to the brain is reduced, and has been used to treat patients with coal-gas poisoning and those with blood clots that reduced the circulation to the brain. It is now being tried in cancer treatment: cancerous tumours

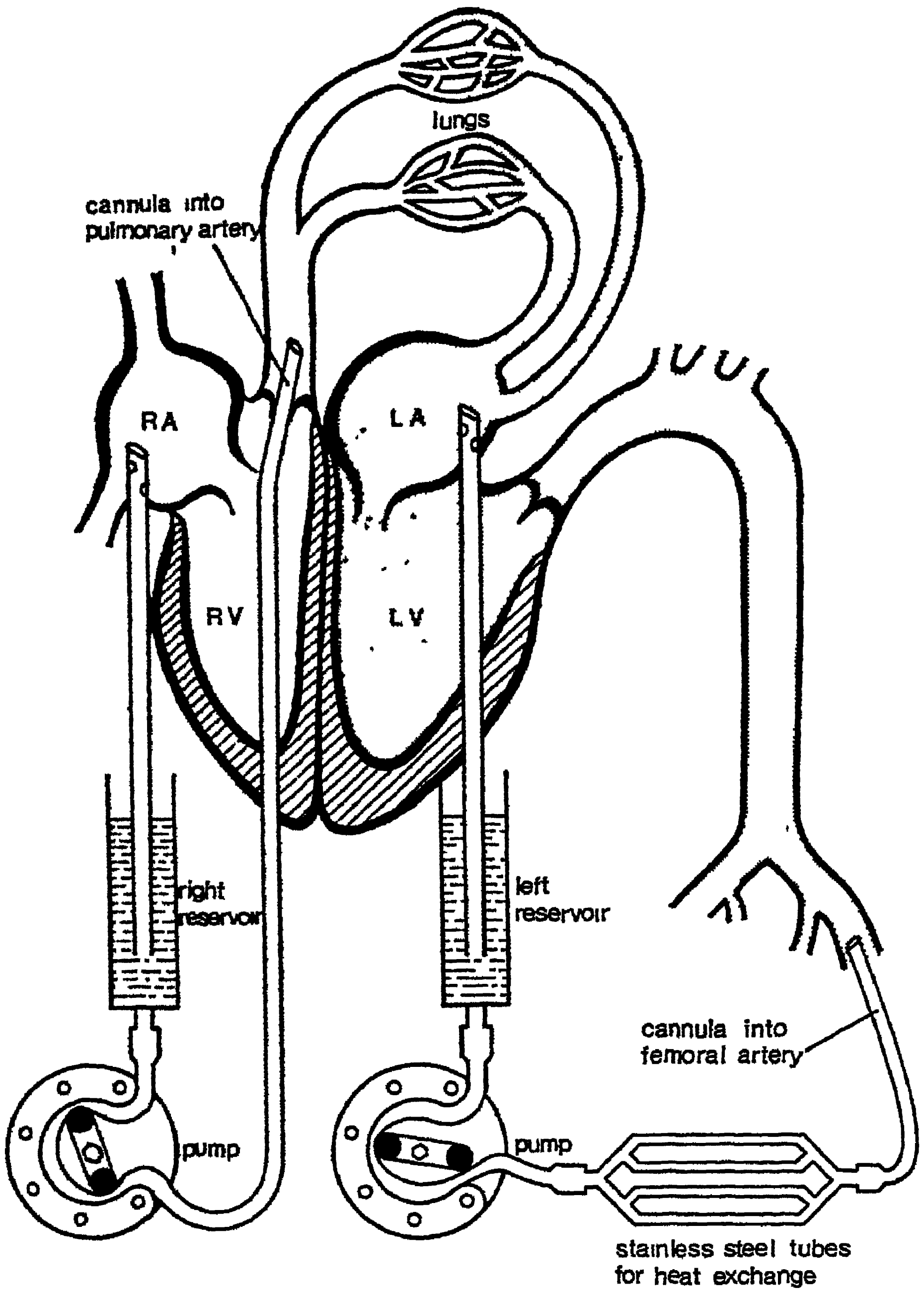


FIG. 5. Hypothermia. The blood does not go through the heart, making surgery very much simpler. In addition, the blood is cooled to reduce the body's demand for oxygen.

are much more markedly affected by X-rays when the oxygen pressure is increased (Pls. XXIV–XXVI).

Hypothermia was valuable in heart operations; so was the heart-lung machine. The next stage was to combine the two. Dr C. Walton Lillehei at Minneapolis solved one problem. The heart, if stopped by chemicals, did not always restart properly. He found that it could be cooled below freezing-point by running cooled blood into it while keeping the rest of the body supplied with blood at the normal temperature from a heart-lung machine. The heart-beat was stopped in this way without using drugs. If the heart was rewarmed it beat normally as it restarted. The drugs had, on the other hand, on occasion produced fibrillation, a rapid and useless fluttering of the heart.

The two techniques were brought together by three surgeons working at the Naval Hospital at Bethesda, Maryland, in an operation in May 1959. The heart-lung machine that they used was fitted with cooling and heating coils, and they started by cooling the anaesthetized patient to 85° F. They then diverted an ice-cold blood supply to the heart to stop it from beating, and suspended its action for twenty minutes while they operated. Finally, the heart was restarted, and then the patient warmed by allowing blood at its normal temperature to flow around the arteries of the body.

The part of the heart-lung machine that gave most trouble was always the artificial lung. Charles Drew, a surgeon at the Westminster Hospital in London, solved this problem by using the body's own lungs. His aim was to short-circuit the blood supply in order to cut out the heart so that it could be cooled and operated on, and to send the blood through cooling tubes, and also through the lungs, so that the blood would be naturally oxygenated. The idea was simple, but mechanically difficult to carry out. The final version used two pumps to do the work of the two ventricles of the heart, and a heat exchanger, so that the circulating blood could be heated or cooled. The complete machine was first used in surgery in 1960.

IV. *Artificial Spare Parts*

IF AN organ is diseased or malfunctioning it can be removed, and the patient must live as best as he can without it; or it can be repaired, often so as to make the organ as good as a normal one. The third possibility is to replace the organ. Crude artificial limbs are as old as history. A complete artificial heart has not yet been made, but it will be in the next few years.

Ambroise Paré, the sixteenth-century father of modern surgery, invented a selection of limbs for the wounded soldiers with whom he was mainly involved (Pl. XXVII. A hand for pulling could be interchanged with a hand that would hold a pen; a hand that could do both—in fact a hand that could even control its grip—had to wait upon recent discoveries of the way that muscles work.

The muscles that cause a hand to grip are set off by an electrical impulse that travels down a nerve connected to the muscle. Electronics experts are quite used to magnifying tiny electrical impulses—radios would not work if amplification were not possible. It should be practicable, therefore, to use the electric impulse of someone whose nervous system was working, but whose limb was missing, to operate an artificial limb. Dr A. H. Bottomley and T. K. Cowell, of St Thomas's Hospital, London, have invented an artificial hand working on these principles that can be used by a person who has had a hand amputated (Fig. 6). Because it uses the same nervous impulses that his own hand did before it was amputated, the man can learn how to use the hand very quickly—within a few minutes.

The hand looks crude. It grips an object, say a teacup, between two covered hooks. The nervous impulse for the gripping action is picked up from a group of muscles on the forearm, amplified, and then smoothed out, since the electrical waves as detected are far from steady. At its simplest this signal could be amplified until it would operate an electric motor that closes the 'hand', but there would be no control over the rate at which the hand closes. This is

obtained by taking a nervous impulse from the set of muscles on the other side of the forearm—the muscles that would oppose the action of the first set if the hand were still there. This impulse is treated in the same way as the first one, and mixed with it before the final amplification. The hand now closes at a controlled rate. Finally, the strength of its grip has to be controlled. The natural hand has a sensitive feed-back that tells the brain how strongly the hand is gripping, so that a hammer is held firmly, an egg gently. It would be difficult to fit the artificial hand with nerves to supply this information, so instead the force that the hand is exerting supplies a signal directly to the motor, and this keeps the grip steady (Fig 6). Pl. XXVIII shows a recent development.

Until recently it was not possible to get batteries that were light enough and yet produced enough power for the limb, so other power sources have had to be used. The Russians, for example, who are very active in this field, have tried compressed carbon dioxide gas. Their limbs have been imported into Britain to be used by babies who have been born with their limbs not fully developed, the result of the use of thalidomide by pregnant women. The nervous system of the babies is quite adequate for operating the artificial limbs.

Otosclerosis is a disease of the middle ear that is one of the commonest causes of deafness in young and middle-aged people—Beethoven was deaf through otosclerosis before he was thirty. Normally the vibrations of the eardrum are carried by a series of bones to the cells that convert them to electrical impulses; in otosclerosis one of these bones is so enlarged that it jams in the gap through which it passes. Dr J. J. Shea of Memphis, Tennessee, has devised an operation to replace this bone, and he claims to restore the hearing of about 90 per cent of his patients. He removes the bone (the stapes), and replaces it with a replica made of the plastic 'Teflon', grafting a thin slice of the patient's own tissue into the gap that is left. The operation, like many ear operations, needs to be done under a low-powered microscope so that the structures of the ear can be clearly seen.

In a way, these are all examples of the less important artificial organs. A patient can live at least a limited life if he has lost an arm or a leg, or if he cannot hear or speak properly. But if his kidneys or his heart fail he dies. It would be wonderful to be able to make artificial vital organs that could be used to replace the defective

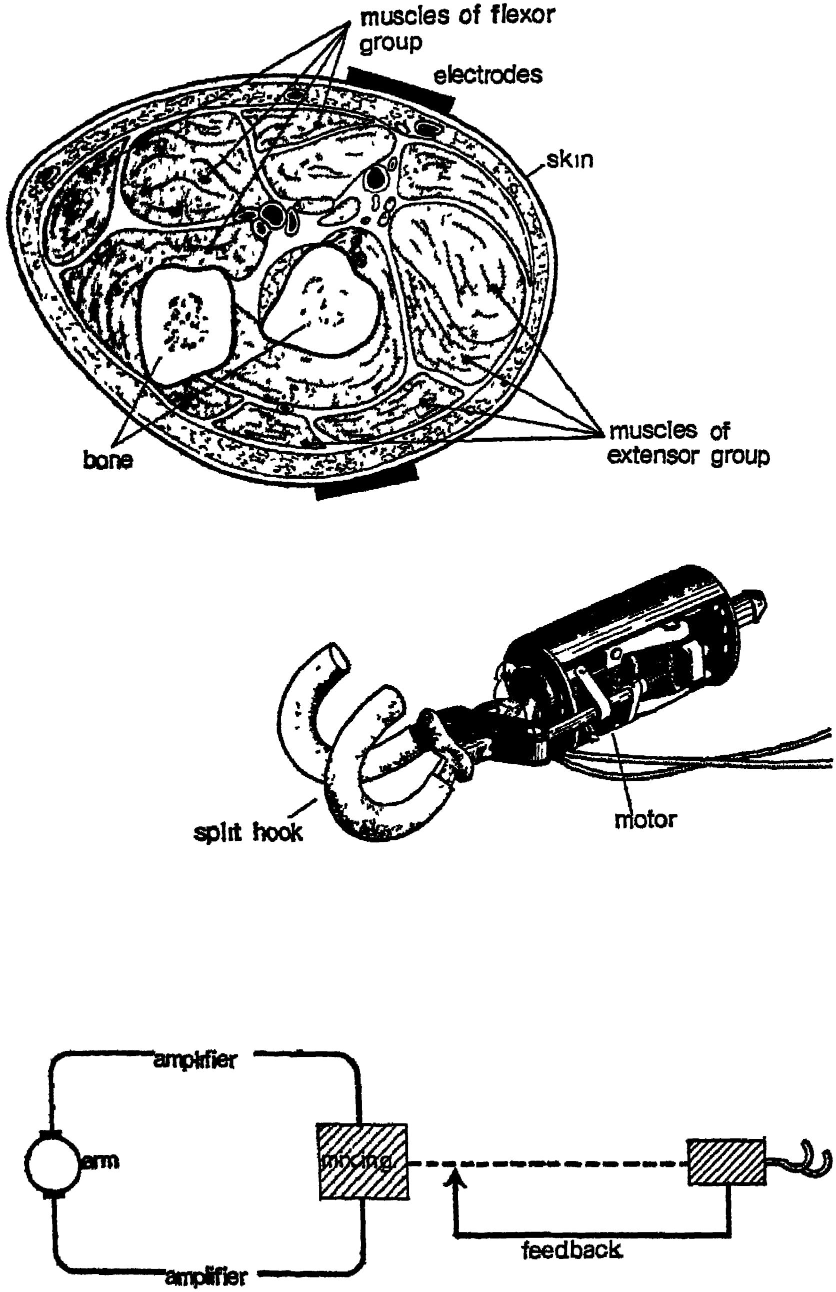


Fig. 6. The artificial hand invented at St Thomas's Hospital, London. Impulses from the nerves of the forearm are amplified and controlled to work the motor which operates the hook.

ones. Even if they were good enough only to be used to keep the patient alive until he was cured, or until he cured himself—some failures are temporary—they would be invaluable.

The artificial kidney has reached this stage. The kidney's job in the body is to take waste products from the blood and pass them to the bladder so that they can be excreted: this is a problem in physical chemistry. The Dr Kolff who first used citrate to stop the heart for an operation was also the first to build an artificial kidney. The design was simple, and he built it during the war, in Holland, while his country was occupied by Nazis. They never knew of his discovery.

Essentially an artificial kidney is a tube that can be connected to a patient's bloodstream, and that will allow the waste products to pass through a membrane into a bath that surrounds the tube. Dr Kolff's membrane was made of sausage skin. This was wound round a drum that revolved in a solution contained in a bath, while the patient's blood was taken to and from the drum by tubes. The solution in the bath has to be so made up that the waste products diffuse into it, while the chemicals—protein, salts, and glucose, for example—that the body needs are kept in the blood.

Kolff's artificial kidney, and more recent developments of it (Pl. XXIX), have saved lives. The human kidneys can fail as a result of the surgical shock that follows a severe injury; this failure is temporary, and soldiers who have been injured in, for example, the Korean war have been kept alive until their own kidneys started again.

The machine is used in peace time as well. The disadvantages are that it is large and has to be operated by an expert: the patient has to come to the machine. And it is not perfect. It gradually dilutes the blood. Furthermore, the modern versions are expensive—it is not possible to provide one for every person whom it would benefit.

Probably the major cause of natural death nowadays is heart disease. But the heart is essentially only a pump, whose entire function is to drive blood around the body to supply its needs. The blood is sent from atrium to ventricle, through a valve, by muscular action, and the ventricles in turn contract so that the blood is sent, again through valves, around the body or to the lungs. The action is mechanical and it should be possible to replace parts of the heart, and eventually the whole of it, by mechanical devices

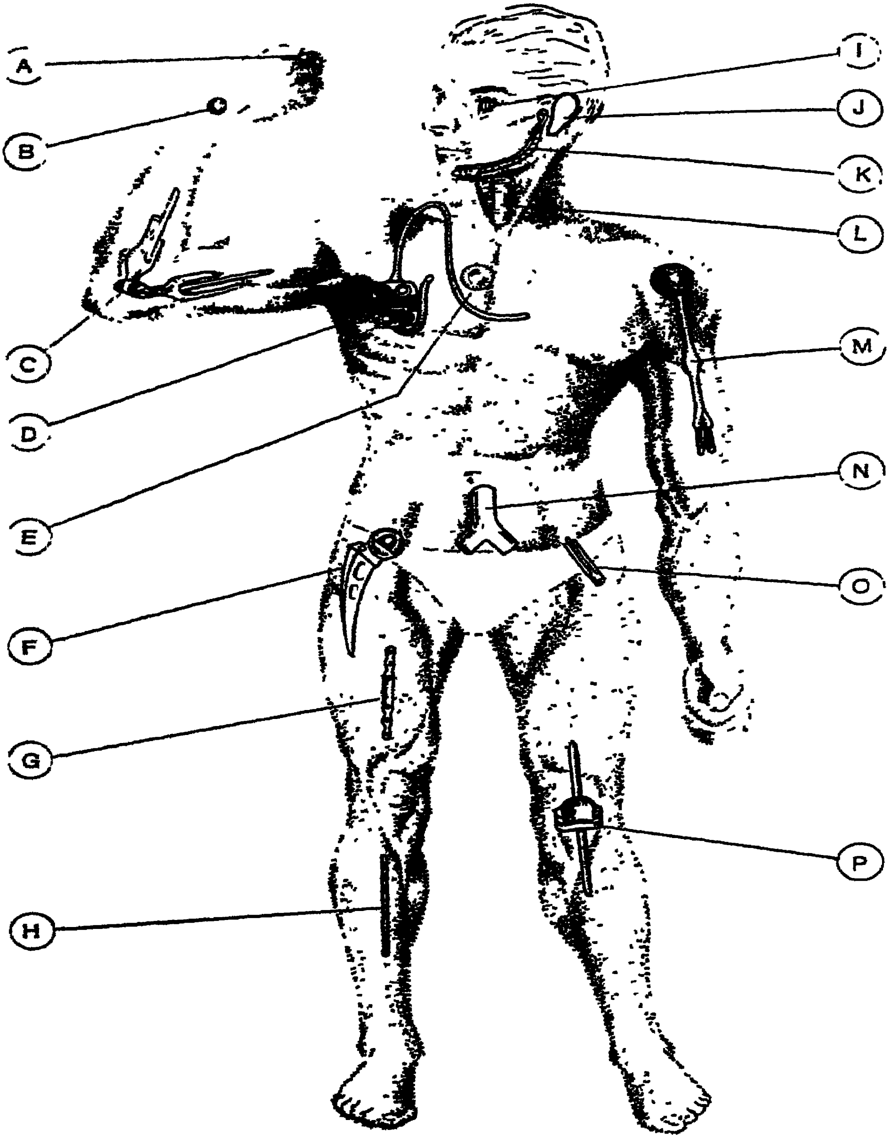


FIG. 7. Artificial 'spare parts'.

A, Mechanical finger joint. B, Metal ball to replace damaged scaphoid bone. C, Hinged elbow joint. D, Pacemaker. E, Artificial valve in heart. F, Hip joint. G, Plate to fortify fractured thigh bone. H, Nail to fix together fragments of a broken shinbone. I, Artificial lens. J, Mould to form basis for skin graft to rebuild ear. K, Artificial lower jaw bone. L, Tube replacing removed portion of gullet. M, Metal replacement for the bone of the upper arm. N, Tubing replacement for diseased aorta. O, Nail for pinning together broken ends in fracture of the neck of the thigh bone. P, Hinged knee joint.

now that heart surgery is possible. There are, however, some vital problems to solve before this can be done.

One is that the body reacts against living material that is put into it—although this reaction can be reduced in some cases—while most artificial materials corrode or decompose. But some do not: a plastic whose scientific name is polytetrafluorethylene (or PTFE) is almost completely inert, and has been used by a number of doctors as a material for artificial heart valves. Another plastic, 'Silastic' (a silicone polymer), has been used to make a ball and cage valve that has been inserted so as to replace a faulty heart valve.

Charles Drew, of Westminster Hospital, has already been mentioned as a heart surgeon. Another of his discoveries is that a plastic mould can be put into a patient's body, and used to make a 'new' heart valve from his own tissues. The mould is partly filled with the patient's tissue, which then grows to fill the mould. The method is successful with animals. If it works with human beings the new valve will be one that can be put into the patient's heart with no fear of its being rejected.

The most serious of all heart diseases is coronary thrombosis. This is a blocking or 'furring up' of the coronary arteries—the arteries that nourish the heart itself. The exact reason for the furring—atherosclerosis is the technical name—is not clear. It affects people from the age of forty on, it seems to affect people who are overweight and who take little exercise more than others, and it may be connected with the kind of food that they eat. If the patient survives the attack that first threatens the heart, new arteries grow to nourish the heart. Dr H. Soroff, of Boston, led a team that devised a pump to support the heart during the attack. Because of the blocked arteries the heart has a great deal of difficulty in pumping. The pump deals with this difficulty by taking blood from an artery near the groin, and then forcing the blood through the coronary arteries so as to nourish the heart until the attack is over. Another way of reducing the strain on the heart caused by the clogged arteries is to replace them with artificial ones made of plastic.

The alternative to making the damaged heart's task easier, or patching it up, is to replace it completely. Dr M. E. DeBakey, of Houston, Texas, has described how he thinks that this will be done. The pump will be a two-walled tube made of plastic, with

the space between the walls filled with air. In versions that are now working, the blood is driven through plastic valves by pumping air from an outside supply to the space between the walls. This air could be supplied internally if an air container were inserted under the skin of the chest and connected by an artificial tendon to one of the large muscles of the shoulder. Dr DeBakey has actually done this with an animal; he used a muscle that is normally attached to the upper part of the forearm, and he stimulated the muscle with an implanted electrical stimulator that gave a regular pulse of

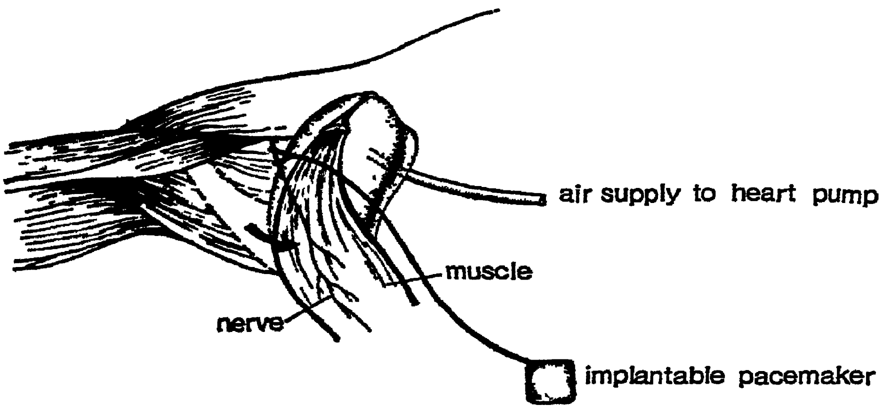


FIG. 8. Dr DeBakey's method of harnessing muscle, stimulated by a pacemaker, to drive an implanted heart pump.

electricity (Fig. 8). The principles of the artificial heart are established, but it is not possible to make one that can be used on a human being permanently—the materials that are used change because they are immersed in the body's fluids and the pumps and valves damage the blood. Once these problems are solved, an artificial heart, fitted when needed, becomes a reality. DeBakey has already fitted a human artificial stand-by heart using an external air supply. Pl. XXX shows one type of artificial heart.

The implanted stimulator mentioned above closely resembles one that was developed to deal with another heart disease. The disease, heart block, shows itself as breathlessness and dizziness, possibly fainting. These are signs that the body and the brain are not receiving an adequate blood supply. The reason in this case is that the lower chambers of the heart—the output chambers—are not contracting at the proper rate. The muscles usually are sound, but they are not receiving the nervous impulse that sets off

the contraction. This impulse starts high up on the right of the heart, and sets off the upper chambers; the impulse then runs down through a knot of muscle and sets off the lower chambers. The chambers of the heart are thus made to contract regularly and in the correct order. If a coronary artery is clogged the connecting muscle may degenerate because it is not getting sufficient nourishment; or the muscle may be cut during a heart operation. The lower chambers will then not get the nervous message, and they will contract at their own rate, which rarely reaches half that of the upper ones.

Electric shocks stimulate muscle, and Dr P. Zoll of the Boston Medical School decided to see if they could be used to treat heart block. Towards the end of 1952 he selected an elderly man in the last stages of heart failure and put one needle under the skin at the apex of the heart, another on the surface. They were connected to an electrical supply that gave a short pulse of electricity between fifty and one hundred times a minute. The source was switched on whenever the heart actually stopped beating and for hours the heart was kept moving and the man kept alive, only by the electric shocks. His heart eventually restarted. The beat was unsatisfactory—the ventricles contracted only slowly—but the man could leave hospital.

The method was crude—it caused muscular spasms, sometimes burns—and it could not be used permanently. Dr C. Walton Lillehei of Minneapolis and two colleagues, W. L. Weirich and V. L. Gott, devised a miniature pacemaker that was connected to the heart during an operation. Again it was a rudimentary version at first; one electrode was connected to the wall of the right ventricle, the other was fitted just beneath the skin, while the pulses of electricity were fed in from outside.

The modern version is one that can be fitted permanently, as at St George's Hospital, London; it is completely implanted and runs from a battery that has to be changed only once every few years (Pl. XXXII) and Fig. 9). The wearer leads a normal, barely encumbered life. Pl. XXXI shows a slightly different version.

There are two other interesting electrical implants. One has been developed to stop bleeding from brain arteries. Dr S. F. Mullan of Chicago has found that the bleeding can be stopped by passing a thin positive electrode right the way through the brain to the bleeding artery, and then completing the circuit with a

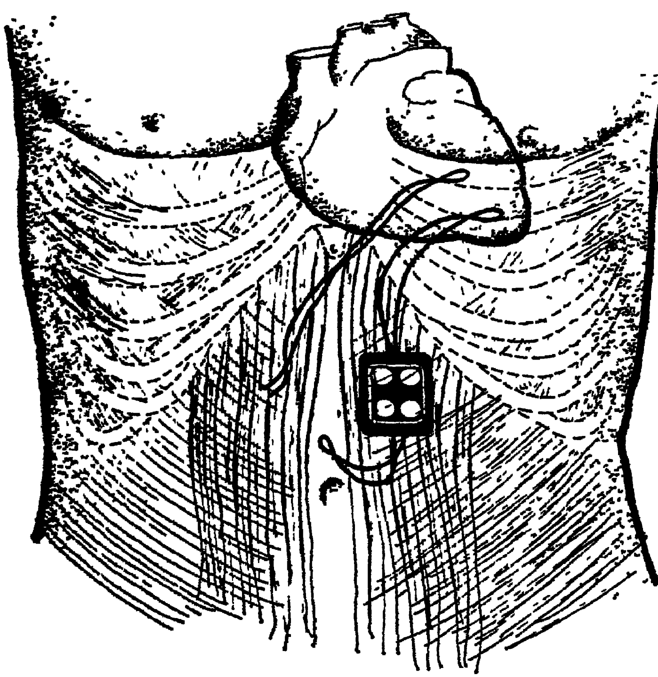


FIG. 9. Implanted pacemaker to cure heart block. The activating electrode is embedded in the heart, together with a spare electrode.

negative electrode attached to the scull. The current quickly causes a clot, and this can be made into a permanent one by inserting a copper needle through the same hole in the skull and leaving it there.

The other device is used to treat high blood pressure. The blood pressure is influenced by the carotid nerve sinuses that occur on each side of the neck. Two different groups in America have found that they can reduce high blood pressure by using electrodes wrapped around the sinus. The electrodes are energized by, in one case, an implanted battery, and in the other, pulses of current picked up by electrodes in the heart. These applications are experimental, but they seem to be successful.

However, these devices are not ideal. The battery can go wrong, the electrodes can work out of place, or the machine itself can corrode. They illustrate the general problems of using artificial vital organs, though the proposed artificial heart illustrates them more clearly. It wears out, it damages the blood, and it may affect the tissues of the patient. Ideally, spare parts should be natural ones.

V. Natural Spare Parts

PEOPLE who are killed in accidents usually die with most of their organs sound. These organs are natural spare parts that could be transplanted into sick people who need them, once the various surgical problems have been solved. Transplants between members of the same species are called homografts; an autograft is an operation in which some part of the body is moved to a new site on the same person. The most familiar example of this is the skin graft, which is used after severe burning. (The first recorded successful skin graft, incidentally, was in the sixteenth century.) The patient's own skin is grafted on to the burn, and eventually new skin grows to replace the patch that was removed for the graft. The autograft is so straightforward that it is used nowadays for 'cosmetic' operations, in plastic surgery.

The problem of transplanting organs between animals has been solved for some time, in the sense that the animals lived for a while after the operations. Demikov, in Russia, grafted the head of a puppy on to the shoulders of a dog in 1959, and there have been hundreds of experiments since then. The animals were usually painlessly destroyed after the operation, for they could not then have led a normal life, but it was thought that the method was basically sound and needed only perfecting. It seemed a promising basis for an addition to the surgeon's repertoire. It was only later, when more research had been done into the way that the body protects itself, that it was realized that the body was actively rejecting the graft.

The rejection—the immune reaction—can be seen in blood transfusion. The blood in the body has several functions—nutrition of the cells, for example—and in this sense it is an organ, although a mobile one. It can be transferred from one person to another, with the proper precautions, and it can be stored until required. Blood transfusion can be thought of as a particular form of transplanting.

The earliest attempts at blood transfusion were generally fatal. Karl Landsteiner showed why this was so in 1900. He found that samples of blood from different people could be divided into two groups that contained, in the red cells, one or other of two substances that he called A and B. Blood that contained substance A in the red cells also contained a substance 'anti-B' in the serum, the colourless liquid that surrounds the red cells. 'Anti-B' would cause any red cells containing B to clump; the cells would appear to curdle. This is known as agglutination, and it causes blockages in blood vessels and capillaries, and this leads to serious damage in the organs that the blood nourishes. These discoveries showed how to make successful blood transfusions (Pls XXXIII and XXXIV).

The red cells of human blood can contain either the A factor, the B factor, both, or neither. The blood concerned is said to be of group A, B, AB, or O, respectively. A person's blood group is determined by his heredity. If the donor and the recipient each have blood of the same group, there will be no clumping and the transfusion will be successful. It was at first thought that there were only two factors, but it is now known that this is an over-simplification. There are more than two, and blood to be used for a transfusion is always tested directly, by mixing some of it with a drop of the patient's blood. It is used only if no clumping occurs.

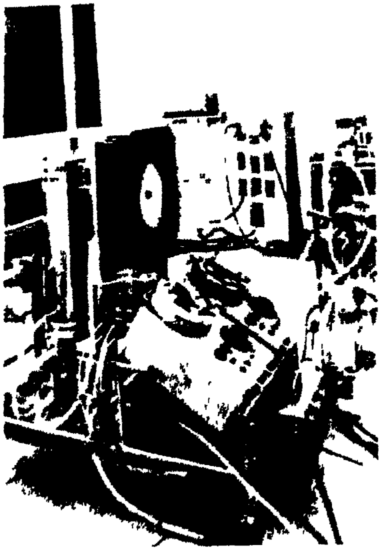
An important discovery was that 'anti-A' and 'anti-B' were not normally present in the blood, but were produced only as a reaction to A or B. This is a particular case of the immune reaction, which is one of the body's defences against invasion by any foreign proteins—that is, any protein material that it did not contain at birth.

One of the reactions to an infection by bacteria or viruses is the formation by certain cells in the blood of what are called antibodies. These remove the bacteria by, for example, dissolving them or forming a precipitate with them. The formation of antibodies is set off by 'antigens' in the invading bacteria or viruses. There may be so many antibodies produced as the result of an infection that germs of that particular type can never again get a foothold. The person will then be immune to the disease caused by the particular germ. This is why some diseases, like measles and mumps, are rarely caught twice. Antibodies are the reaction to an invasion by a particular kind of germ or virus; they will generally have no effect on infection by any others. (There are some exceptions to this rule.

XIX An operation freezes some cells in the brain, and can stop in a minute tremors of the hand (Parkinson's Disease) that have been going on for twenty years. (*See also* frontispiece.)

XX Re-attaching a retina with a laser.

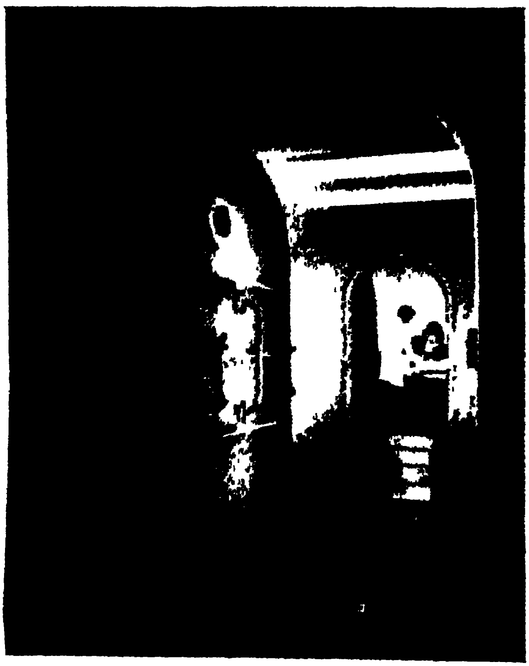
XXI A heart-lung machine outside the operating theatre takes over the functions of the patient's heart and lungs during the operation. The pumping system is on the left and the tanks in which the patient's blood is oxygenated are on the right.



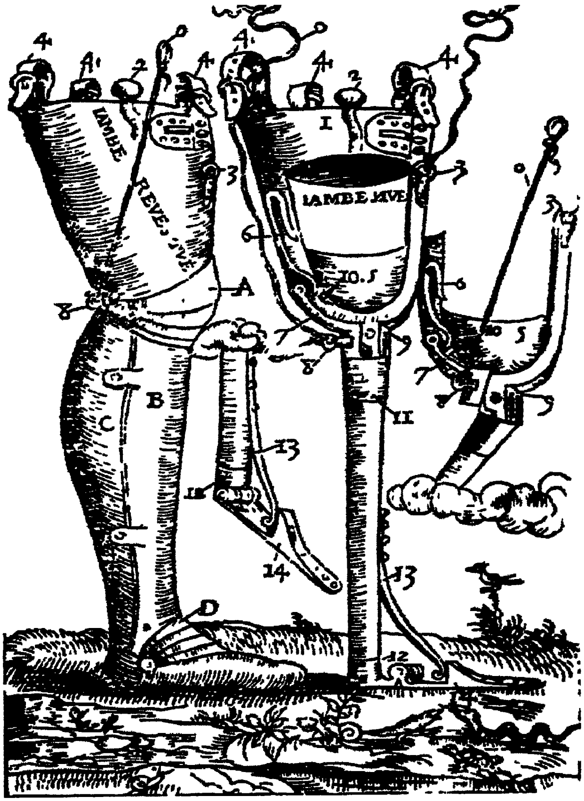
XXII *Left:* This machine is used to cool the patient's blood (hypothermia) for long enough to perform a heart operation without damaging the brain by interrupting its blood supply.

XXIII *Right:* The heart is opened under hypothermia, which gives the surgeon a safe time of about ten minutes.

XXIV *Below:* A patient in an individual high-pressure oxygen chamber, used for treatment.

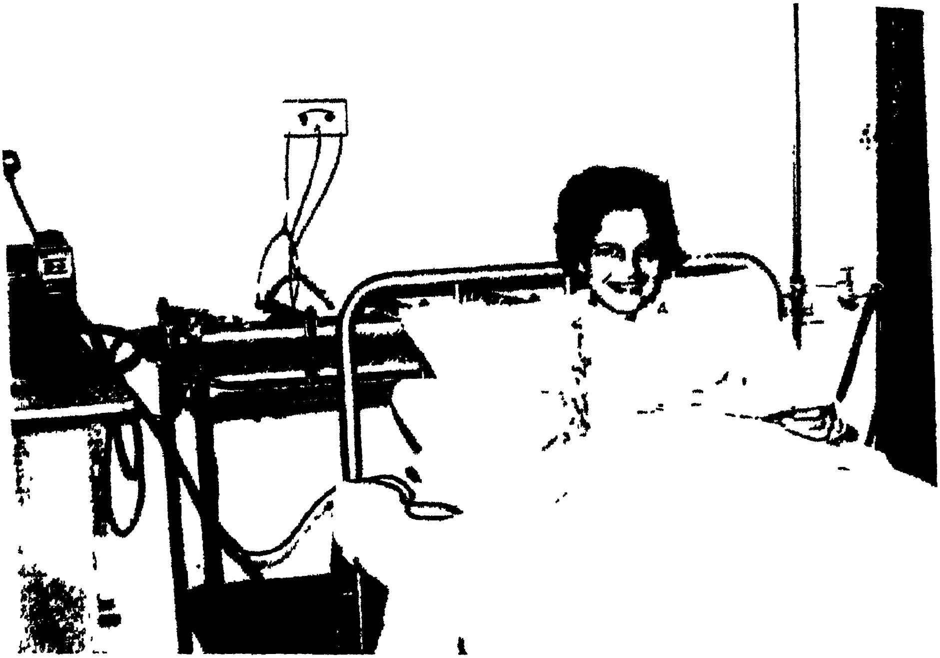


XXV, XXVI A large high-pressure oxygen chamber which can be used both for medical treatment and as an operating theatre.



XXVII An artificial leg made by Ambroise Pare, the sixteenth-century 'father of modern surgery'.

XXVIII A natural-looking artificial hand that uses the body's own electrical impulses to produce its movements.

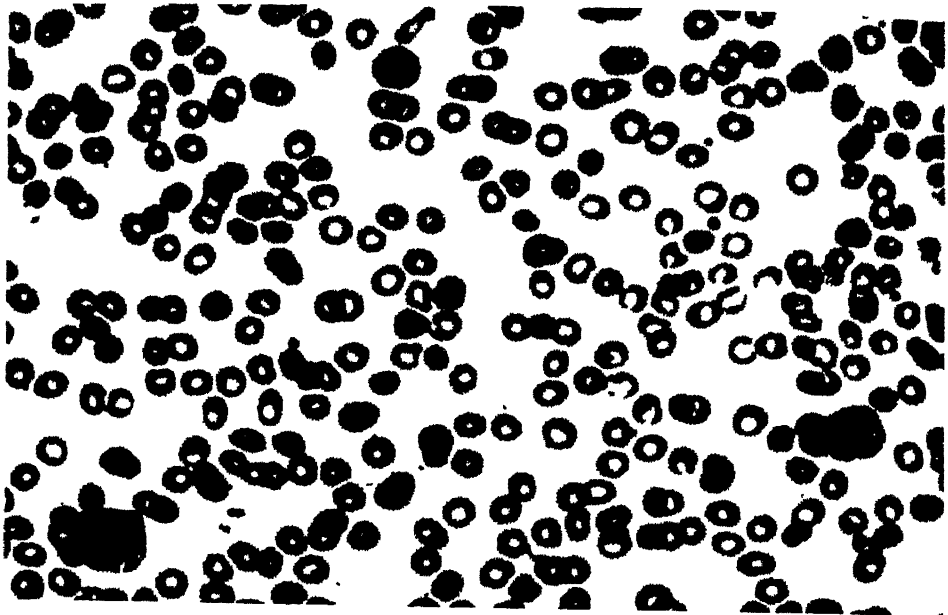


XXIX A patient attached to an artificial kidney.

XXX An artificial heart made of plastic.

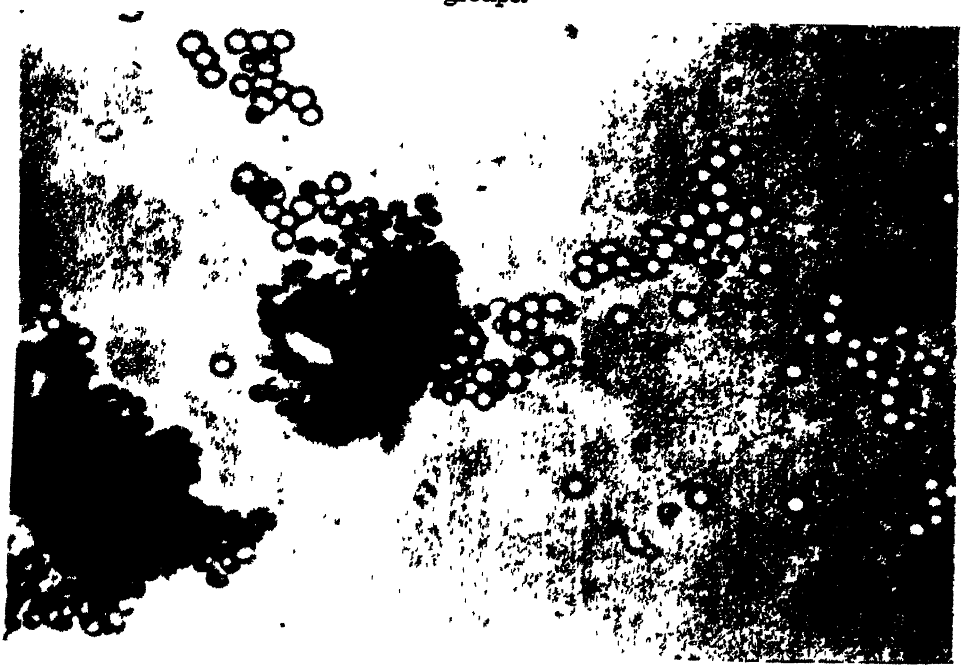
XXXI The patient wears an internal pacemaker, as shown in the X-ray picture on the left, to keep her heart beating regularly. The surgeon is holding a model of a pacemaker which can be carried in a pocket or worn around the neck, as shown in the right-hand X-ray picture. It would be wired through the skin to the heart.

XXXII X-ray photograph of pacemaker completely implanted and run on a battery.



XXXIII *Above:* Normal blood cells as they appear under the microscope.

XXXIV *Below:* Clumping of blood cells resulting from mixing incompatible groups.



The antibodies that result from an infection by cowpox protect against smallpox, for example.)

This immune reaction is one of the body's protections against harmful invasions. Unfortunately it cannot distinguish harmful ones from beneficial ones, and a blood transfusion of the wrong group will be rejected. An organ transplanted from the wrong person will also be rejected, and the choice of a suitable donor is much more difficult than it is for blood transfusion. The only acceptable organ is one from someone who is genetically absolutely the same—that is an identical twin. In this case the body cannot distinguish between its own organs and the grafted ones.

It is not at present clear whether the rejection mechanism in other cases is more complicated than merely the formation of antibodies. But whatever it is it must be damped down if the graft is to succeed. This can be done by either drugs or X-rays. One group of drugs, the alkylating agents, has the same effects on antibody formation as X-rays—they damage the cells of the blood so that they do not produce antibodies. Another group, the antimetabolites, so called because they interfere with the metabolic processes of the cells, prevents antibody formation by this interference.

There are two kinds of problem. First, the dose of drug or X-ray that is powerful enough to make the graft effective may permanently damage the patient. Secondly, the treatment lowers the body's resistance to all kinds of invasion. The patient then has a very low resistance to infection both of the wound and of himself. He must be kept in a completely sterile atmosphere during the operation and after it, until his own defence mechanism is working properly. There have been a number of cases where the operation has been successful, in that the grafted organ has started functioning, but the patient has died of an infection such as pneumonia. Thus a completely sterile hospital, isolated from the outside world, is needed for successful transplantations. There are, incidentally, other treatments that need a hospital of this type, and one is being built in London for the cure of a rare kind of cancer that affects women. The cure uses drugs that temporarily lower the women's resistance to infection.

Let us have a look at a typical transplanting operation—that of a kidney. The patient showed the typical symptoms of kidney failure—his blood contained large quantities of the urea that the

kidneys should have been removing, and he was excreting very little urine. He was getting worse despite treatment. A transplant was therefore suggested—it is so dangerous that it is used only after all other treatments have failed. The first problem is to find a spare kidney, and in this case the patient's father volunteered to give one of his two kidneys, and the doctors found that they were both healthy. There is always some risk in removing a kidney—partly the direct risk of the operation, and partly the possibility

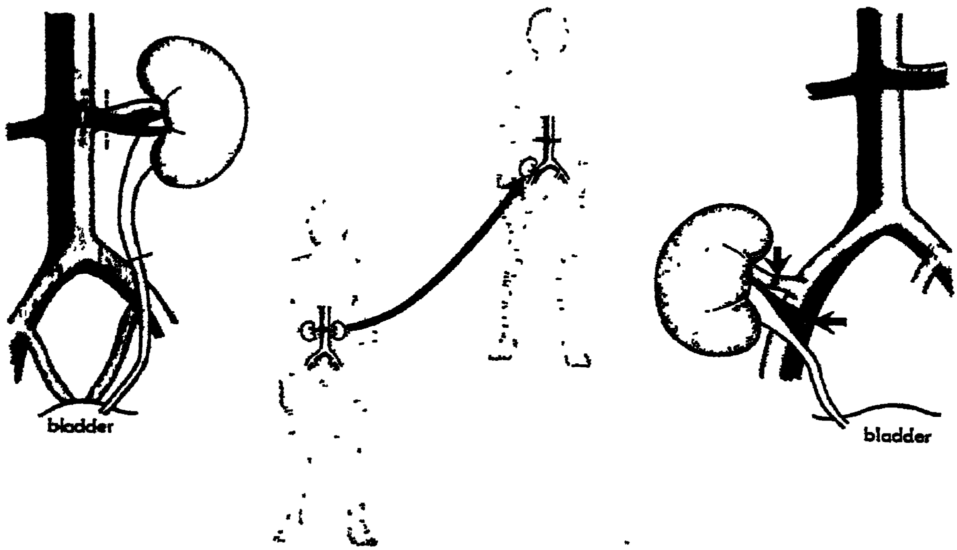


FIG. 10. Kidney transplant; donor at left.

that the remaining one may fail later, or may not be up to the demands of the body. However, the father was fit and active, and all his other children were self-supporting. The father and son were of the same main blood group, O, and the other factors matched sufficiently closely for there to be no reaction when their blood was mixed.

An artificial kidney was used to purify the youth's blood before the operation. Unfortunately the operation had to be delayed, and the concentration of urea in the blood became four times as great in eleven days. The doctors decided to operate. The youth was given drugs to reduce his reaction against the new kidney, and one of his father's kidneys was inserted. It was put in near the pelvis, and the artery and vein of the kidney were connected to an artery

and vein that ran near by. The kidney, if the operation succeeded, would purify the blood that ran into it. It was connected to the bladder so that the impurities could be discharged in the urine. The surgical part of the operation, which is not formidably difficult, was over (Fig. 10).

The testing time followed. The first good sign was that the patient felt better when he recovered from the anaesthetic than he did before the operation; patients who need a kidney transplant feel very ill indeed. The next good signs were that the patient started passing urine, and that samples of his blood showed that the concentration of waste products was going down. The kidney was working. The patient was kept in hospital, and given more or less daily doses of the drug that had been chosen as a 'rejection reducer'. Ten days after the operation the patient began to run a temperature, and he complained of discomfort two days after this. These troubles could well have been caused by the drug, so it was discontinued. However, he continued to deteriorate, and started to pass less urine. There was no sign of infection, so it was assumed that all of the troubles were due to a rejection reaction, and the drug was restarted. The kidney started working again, but a check on the blood showed the number of white cells in it was falling rapidly. This was a sign of an extremely dangerous state. The drug worked by interfering with the action of the cells, and it was clearly the source of the danger, so it was again stopped. Now the rejection was unchecked. The kidney stopped working, and the graft became painful and could be felt as a mass from outside. This degeneration was not affected by using an alternative drug, so the doctors turned to the first one again. This stopped all the signs and symptoms directly connected with the graft—the pain and the swellings—but the kidney did not start working again. The concentration of impurities in the blood rose and the patient more or less stopped passing urine. He died seven weeks after the operation, probably because the graft reaction, once it had started, was not sufficiently reversed by the drugs.

At present these operations frequently fail. The death may be due to a reaction against the graft, as in this case; it may be due to an infection that strikes the patient when his resistance has been lowered; or he may die from the action of the drugs themselves. Dr J. Murray, of Peter Bent Brigham Hospital, in Boston, has commented on the results of 244 kidney homografts. Seven out of

the twenty-eight patients who received a kidney from an identical twin had died, and this is the most promising kind of transplant. Of 120 whose grafted kidneys had come from unrelated donors, only one who survived the operation longer than a year was still alive. However, other reports are more encouraging. Four patients were still alive a year after they had received kidneys from unrelated dead people. The successful control of the reaction was important, but the fact that the kidneys came from dead people was in a way more striking—any risk in the operation was confined to the receiver.

These kidneys came from people immediately after they had died: there is no satisfactory way of preserving human kidneys, although there has been some success in preserving dog kidneys by freezing them. In a human transplant the receiver has to be taken to hospital when there is a suitable dying person, usually an accident victim.

A homograft that is so frequently successful that it has become a routine operation is that of the cornea. This is the hard transparent part of the eye, the part on the surface that lets the light in. (It is the only completely transparent part of the body.) It seems black when we look at it because we are looking at the dark inside of the eyeball. If it becomes infected it may become opaque, and somebody with an otherwise satisfactory eye will become blind. Injury—a scratch or a burn from lime—can give the same result.

The delicate operation of grafting on a new cornea from a corpse was tried in the nineteenth century, but it failed, because of bad technique or infection. Nowadays, even in grafts in which the eyeball is opened, only one in fifty fails because of infection, and the transplanting of corneas to patients whose own are defective is successful in nine cases out of ten. The main reason for the very high rate of success is that there is no immune reaction. This is because the immune reaction is produced by cells in the blood, and the eye is not nourished by a blood supply.

The main problem now in corneal grafting is getting a supply of healthy eyes to the surgeons. With very few exceptions these eyes come from dead bodies. For a long while there were legal difficulties, but these have now been partly solved. The eyes cannot be taken from a body without permission, and a dying person is frequently in no state to give it. But an Act of Parliament that was

passed in Britain in 1952 made it possible for people to give permission long in advance. Other countries have similar laws. The practical difficulties are less easily solved. The eye has to be removed within twelve hours of death, and used within two days, or three at the most, if the operation is to have the maximum chance of success. This means that there has to be an organization telling every eye-graft surgeon which donor eyes are available, so that he can plan his operations. It would be a great advance to discover a way to store the eyes for a longer time after removal. Rabbits' eyes have been stored for up to a month in a deep-freeze, after treatment with glycerol and dimethyl sulphoxide, and then successfully grafted; there have been a few successes after storing human eyes as long. If this method, or one like it, can be made completely reliable, the main problems of grafting corneas will have been solved.

There are other parts of the body that can be grafted with a high proportion of success. Cartilage is the translucent elastic substance that covers the ends of bones in joints, such as the knee, that allow a lot of movement, and it forms part of the connective tissue that allows the joints of the spine, or those where the ribs meet the breastbone, their limited movement. Cartilage is not nourished by the bloodstream, so that the successes in grafting it are not particularly surprising. More striking is the homografting of the aortic valve of the heart. This gives yet another treatment, in addition to replacement by artificial valves, and growing a new valve inside the patient. Two different groups of doctors, one under D. Ross and the other under B. G. Barratt-Boyes, have recently reported that they have grafted a total of eighty-two valves. All but five of the patients seem to have been successfully treated, and most have been alive for at least fifteen months after the operation. The high rate of success is striking; even more so is the fact that the valves had all been stored, by freeze drying, for a long time before the operation. The doctors concerned think that there may be very little immune reaction, if any, in this case.

Grafts where the immune reaction is important would be more likely to succeed if it were possible to choose organs that the patient did not react strongly against, for then the dose of drugs or X-rays could be kept down. He will react more strongly against organs from some people than against those from others. If the doctors are fortunate enough to have a choice of donors, they need

a way of selecting the most acceptable one, and even if they have no choice, a measurement of the strength of the likely reaction helps them to decide on the amount of preliminary treatment to use.

There are two ways of making the selection. One has been developed by Dr P. B. Medawar and Dr L. Brent of the National Institute for Medical Research in London. They worked from the fact that the main function of the lymphocytes—a group of white cells in the blood—is to protect the body from invasion. It isn't exactly clear what part they play, but the test can be carried out without knowing this. Samples of the blood lymphocytes from the patient are injected under the skin of each of the potential donors. There will be a reaction—a red swelling—relatively quickly; it usually takes less than twenty-four hours. This reaction is that of the recipient against the donor, and the strength of the reaction is a measure of the strength of the antagonism. This method of classifying potential donors works well for guinea pigs. It should work for human beings, and if it does, it means that the surgeons can quickly pick out the donor whose organ will be least powerfully rejected by the patient. He will therefore need a relatively small dose of X-rays or drugs, which reduces the chance of dangerous side effects. Dr K. Hirschhorn and Dr F. Bach, of New York University, have suggested another approach. They found that they could mix the lymphocytes of patient and donor in a test-tube and get a reaction—the cells became overactive, and enlarged and multiplied—that measured the strength of the immune reaction between them. Doctors using this method hope that it will give them a guide to the rejection process during the period after the operation. They can take samples of the patient's lymphocytes after the operation, and watch how they develop a reaction against the cells of the donor.

The other way of selecting a donor who will not provoke a strong reaction is to 'type' people for organs as they are now typed for blood. We can say that it is fairly certain that a person whose blood is group AB, rhesus positive, will accept blood transfusions from someone else whose blood has the same factors, and research workers are trying to recognize factors in organs that could be used to group them. Unfortunately there are a lot of them—fifteen factors that affect grafts have been found in mice. However, they are not all equally important, so that this approach may turn out to be valuable.

Most of the transplanting operations have been with kidneys. They are relatively simple organs to connect, and small enough to be tucked into the body without having to remove anything else to make space. In addition, a normal person has two healthy kidneys, so that he has one to spare for someone who might otherwise die. Operating on a healthy person is not ideal, medically, but it does give a source of healthy organs. The number of successful kidney transplants using relatives as donors is small, as is the number using unrelated dead people, but it is encouraging. The transfer of other organs is much less successful.

There have been a few attempts to transfer the liver. One problem is that it is a large organ, and there is no space for a spare one in the body. Removing the patient's own liver, and keeping him alive until the spare is working, is very difficult. Another problem is that the organ is complex, difficult to connect, and easily damaged; and it has to come from a dead person, as no one has a spare. So far there have been no long-term survivors. Of three patients operated on by a group under T. E. Starzl in Denver, United States, the longest-lived survived only twenty-two days. However, in his case and one of the others, the graft had not been rejected, and death was due to complications that might well have been the result of damage to the liver in moving it.

There has been one reported attempt to date at transplanting a lung. A group under J. C. Hardy at Jackson, Mississippi, transplanted one from a dead person into a man who was suffering from lung cancer and kidney disease. The rejection was damped with drugs, and the operation apparently succeeded. However, the man died because his kidneys failed eighteen days after the operation.

Transplanting operations will gradually become more common and more successful. The problems—the surgery, preventing rejection, and keeping the patient healthy while his resistance is low—have all been solved in some of the cases. Unless the use of organs from other animals or the storing of organs from dead people becomes common, the supply of sufficient spares is going to be the major hindrance in the future.

The decision as to whether to use natural spare parts or artificial ones will, in the future, be partly decided on the grounds of which works the better, or which is the more easily available. It is likely, though, that the use of natural spare parts will also raise serious

ethical questions. There will probably never be a sufficient supply of organs from accident victims; this implies that the organs will have to come from donors who are willing to give a kidney, for example, because both of their own are functioning well. Surgeons are bound to be unhappy about this—it involves operating on a healthy person and putting his life at risk. It may well be that objections of this sort, and the improvement of artificial spare parts, will mean that natural spare part surgery will have only a small place in the future.

VI. Careers in Surgery

THE career in surgery that comes most quickly to mind is that of a surgeon. The Royal College of Surgeons of England, Lincoln's Inn Fields, London, W.C.2, can supply all the information that you will need about how to become a surgeon. Very briefly, the would-be surgeon leaves school with sufficient A-level subjects for admission to a university or a medical school. He or she (there are both men and women surgeons) will first qualify as a doctor, and can then specialize as a surgeon. Once qualified as a doctor, there are other careers open that are connected with surgery. It is, for example, possible to specialize in anaesthesia, or in radiology (the interpretation of X-ray pictures).

There are a number of careers open to those who are not doctors, but who have graduated from a university or a college of advanced technology. Modern surgery uses such complex apparatus that there are always physicists working with the surgical team in the operating theatre. In England a high percentage of this work will be in the treatment of patients with X-rays; Scotland uses clinical physicists for purposes that might involve any one of a very wide range of particular interests in physics. Surgery nowadays also needs those whose interests are in engineering rather than in physics. They will work in plastic and accident surgery, making sure that the new structures are properly designed; and they will work on devising and operating the apparatus that the anaesthetist must use.

Physics technicians also work in the operating theatre. They will take some O-level subjects at school, and then take a National Certificate, and possibly a Higher National Certificate, in applied physics. Their jobs will probably use electronics, or isotopes, or the devising and working of scientific instruments. If they should eventually decide that they do not wish to continue working in hospitals there are interesting and rewarding jobs for them in industry.

This also applies to those who have one of the qualifications—the first is as an Associate—of the Institute of Medical Laboratory Technology. The Institute's address is 74 New Cavendish Street, London, W.1, and you can get further information from there. The preliminary qualifications you will need are some O-level subjects. Once you have the qualifications your work will be in the laboratories attached to a hospital.

There are other careers that can be started by someone with some O-level subjects. Examples of these are in physiotherapy, in radiography (the taking of X-ray pictures), photography, and as a medical artist. The Chartered Society of Physiotherapy, Tavistock House South, Tavistock Square, London, W.C.1, and the Society of Radiographers, 32 Welbeck Street, London, W.1, can supply information about the first two.

Nursing, of course, is another career connected with surgery. You can get information about this from the General Nursing Council for England and Wales, 23 Portland Place, London, W.1, or the General Nursing Council for Scotland, 5 Darnaway Street, Edinburgh 3.

Books and Magazines

RESEARCH of the kind described in this book is progressing very rapidly, and the best popular sources of information about the latest progress are the magazines *Discovery*, *New Scientist*, *Science Journal* and *Scientific American*. Anyone interested in the earlier work will find a good description in *A Short History of Medicine* by Charles Singer and E. Ashworth Underwood, second edition (Clarendon Press: Oxford University Press, Oxford, 1962). More recent work is dealt with in *The Risk Takers* by Hugh McLeave (Frederick Muller Ltd, London, 1962) and *Modern Medical Discoveries* by J. G. Thwaites (Routledge & Kegan Paul Ltd, London, 1958).

Index